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An Evaluation of Clearwing Borer Activity in East Tennessee in Relation to Color, Growing Degree-Days and Pheromone Lure Brands

Christopher Dean Vaughn
University of Tennessee, Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Christopher Dean Vaughn entitled "An Evaluation of Clearwing Borer Activity in East Tennessee in Relation to Color, Growing Degree-Days and Pheromone Lure Brands." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant Sciences.

William E. Klingeman, III, Major Professor

We have read this thesis and recommend its acceptance:

Frank A. Hale, Jerome Grant

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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An Evaluation of Clearwing Borer Activity in East Tennessee in Relation to Color, Growing Degree-Days and Pheromone Lure Brands

A Thesis

Presented for the

Master of Science Degree

The University of Tennessee, Knoxville

Christopher Dean Vaughn

May 2005

DEDICATION

This thesis is dedicated to Dr. W. Klingeman, my wife Anne Vaughn and sons Elliot and Max, my parents Dan and Beverly Vaughn, the staff at Mr. Green Thumb, Jay Shilling, Dennis Whittington and all my other friends. Thank you for your patience, encouragement and love in helping me achieve a Master's Degree.

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Abstract

Different species of clearwing moths are known to prefer slightly different pheromone chemical ratios in their long-range mating attraction. Attraction to pheromones is primarily an olfactory response. Olfactory cues are utilized for long-range attraction, but short-range visual cues may also contribute to orientation and mating success of the male clearwing males. To investigate the hypothesis that color and olfactory cues influence male clearwing attraction, a study was initiated in 2002.

Experimental treatments included trap orientation, color and pheromone blends in conjunction with Multipher-1 traps. Clearwing moth trap catches in East Tennessee were pooled across species and analyzed by black, green and white painted traps. For pooled sesiid species and for the lilac borer, *Podosesia syringae* (Harris) and the peachtree borer, *Synanthedon exitiosa* (Say), trap color did not influence the number of adult male sesiids captured.

During 2003 trapping, painted traps yielded a total of 990 male sesiid moths pooled among the 5 different commercially-available dogwood borer lures. Captured moths represented 11 different clearwing borer species. Only 3 dogwood borers were captured in 2003: the Scenturion lure No. 149, the European dogwood borer test lure and IPM Tech's DWB lure each caught a single *S. scitula*.

A second study was initiated in 2003 at three study sites to evaluate the effectiveness of five commercially available lures marketed to trap male dogwood borer. The commercial lures attracted 13 different clearwing borer species and captured a total of 1,121 male moths. Of this total only 3 were dogwood borer. This prevented

monitoring seasonal flight activity of the dogwood borer. However, this research documented the species diversity of non-target sessids collected using commercially marketed dogwood borer lures that are marketed and sold for landscape IPM monitoring. While these commercially-available pheromone lures do not reliably monitor adult male dogwood borer flight activity, they still provide useful tools for monitoring other adult male clearwing borer species.

In 2002 and 2003, these commercial lures were used to monitor the seasonal flight activities of adult male lilac borers and peachtree borers. Trap capture data were compared to growing degree-day (GDD) accumulations using a base temperature threshold of 50°F (10° C) during both seasons for these moth species. Seasonal trap catch yields showed that lilac borer was first collected and active 9 April after 107 GDD and after 165 GDD had accumulated in 2002 and 2003, respectively. Male moths remained active throughout 12 June, and 26 June, in 2002 and 2003, respectively. The first trap catch of *Synanthedon exitiosa* (Say) occurred 11 May 2002 after 572 GDD and 1 July, subsequent to 1550 GDD accumulation. Flight activity in both years peaked between 29 June and 26 August. The discrepancy between accumulated GDD in 2002 and 2003 and first trap is not readily explained. Growing Degree Day accumulations are dependent on weather. Seasonal abundance of cloudy and rainy days reduces accumulated GDD. The lower rainfall totals in May 2002 may explain the reason for an earlier flight emergence of *S. exitiosa*.

Results of this study are expected to provide IPM scouts with a better understanding of the seasonal activity of clearwing moths in Tennessee. Early detection and control of clearwing moths will help reduce chemical dependency by properly timing applications and prevent economic and aesthetic injury to the urban landscape.

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A Role for Integrated Pest Management in Clearwing Borer (Lepidoptera: Sessidae) Management

The Green Industry in the United States has become a multi-billion dollar industry. Each year, homeowners and businesses have landscape architects design urban environments that management professionals must implement and maintain. Once woody plants, especially trees, become established in the urban environment their value increases. In 1990, the value of the urban forest was estimated between $18 and 30 billion. In addition to urban street trees, about 600 million additional trees exist in homeowner's lawns and in parks throughout the United States (Raupp et al., 1992).

With the increase in landscape development, both abiotic and biotic factors predispose ornamental plants to insect and pathogen attack. Abiotic factors include drought, sunscald, transplant shock, poor site selection, injuries by natural events or man (pruning and mechanical injuries), and construction activities. Biotic factors consist of living organisms such as pathogens and insects (Agrios, 1997). One biotic factor of increasing concern is the vascular damage done by the wood-boring insects often referred to as "borers." The majority of borers that damage susceptible trees and shrubs are represented by three families of beetles: metallic wood- boring beetles (Buprestidae), long-horned beetles (Cerambycidae), engraver or bark beetles and ambrosia or timber beetles (Scolytidae). Other beetle families include Bostrichidae, Lymexylidae, Brentidae, Curculionidae and Platypodidae (Solomon, 1995). Moths in two families, Sesiidae and Tortricidae, also have larvae that damage woody tissue (Raupp, 2001). Additional families of Lepidoptera with wood-boring species are Hepialidea, Nepticulidae, momphidae, Gelechiidae, Argyresthiidae, Cossidae, Pyralidae, Thyrididae, Pterophoridae, and Noctuidae (Solomon, 1995). The order Hymenoptera also has wood borers in four families; the Tenthredinidae, Siricidae, Xiphydriidae, and Cephidae while the Diptera have one family: Agromyzidae that are cambium miners (Solomon, 1995).

Borers rarely attack a healthy plant. Rather, borers are opportunists and initiate an attack when plants are injured, stressed, or in decline. Both plant stress and feeding injury of arthropods weaken plant defenses, accelerate plant decline, and initiate a release of volatile compounds into the atmosphere. These volatile compounds are detected by a wide variety of borers, which then infest the weakened plant. Once susceptible trees (such as, dogwood, ash, lilac, poplar, and black gum) and shrubs are infested, they can become brood sites for borers to increase local populations (Mitton and Sturgeon, 1982).

Integrated Pest Management

Integrated Pest Management (IPM) was developed to maximize agricultural production while minimizing the potential for exposure and over-reliance on pesticides in the biosphere. The goal of an IPM program is not the eradication of all pests, but rather to maintain pest populations below an economic or aesthetic injury level. IPM relies on the coordinated use of the best available pest management tools to prevent unacceptable levels of plant damage in production systems and the landscape. While determining the management tool, the IPM scout must consider the economic, ecological and societal consequences (Grant, pers. comm. 2003).

In developing an IPM program several basic components must be established: prevention, pest identification and knowledge of the lifecycle of pests, monitoring, economic or aesthetic thresholds, and management tools. These management tools include cultural, mechanical, biological, and chemical control. The final components of the IPM approach are thorough record keeping and evaluation.

Prevention

The most important management tool an IPM scout has is to grow the healthiest trees possible. Cultural control should be the first choice in IPM arsenal of defense. Cultural control deliberately manipulates an environment to make it unsuitable for pest establishment. Cultural controls in ornamental landscapes are similar to those used in agronomic systems and include sanitation, removal of leaves that may support inoculums and pests, pruning infected plant parts, and completely destroying heavily infested or infected plants.

Another cultural control method is the use of plants that are less susceptible to pest attack, such as *Cornus kousa* resistance to *Synanthedon scitula, Cotoneaster* var. *adpressus* var. *praecox* resistant to fireblight, and *Juniper chinensis* resistance to Phomopsis Tip Blight (Smith-Fiola, 1991). During planting avoid physical injury to the plant, try to reduce transplant shock, consider location of plants and their mature plant size, provide adequate spacing, and use separate irrigation zones. Keeping plants healthy by proper watering and adequate fertilizer are less likely to be attacked by borers and disease (Grant, 2002).

Identification and Sesiid Lifecycles

To make well- informed decisions about the methods of control, a basic knowledge of the specific pest is required. The first step is to determine whether a biotic pest is causing the problem and what are the plant symptoms. Regardless, whether it is a disease pathogen or an insect, proper identification is a necessary first step. Many insects found on landscape plants are transients or beneficials. It is vital to preserve beneficial arthropods like the green lacewing, *Chrysoperla carnea,* mealybug destroyers, *Cryptolaemus montrouzieri*, and female ectoparasitic wasps, *Aphytis* (Flint and Dreistadt, 1998). Once an insect or mite has been identified as a pest, understanding the pests seasonal life cycle, number of generations it completes each year, degree of infestation, potential for further damage, and natural enemies help determine prescribed treatments (Hale, 2001).

Monitoring

Monitoring pests is crucial to the success of tree and shrub pest management programs. Through monitoring, regular inspections are used to identify infested plants. Only those plants that are damaged at or above an economic or aesthetic threshold are treated. Monitoring also provides valuable data regarding the seasonal activity and specific developmental stages of arthropod pests (Raupp, 1985). Another benefit of monitoring allows for more accurate timing of pesticide applications that target the most susceptible life stages of the pest.

Clearwing moths emerge at various times of the day depending on the species type. Generally, moths of the Sesiidae emerge during daylight hours. For example, *Synanthedon exitiosa* (Say), *Synanthedon pictipes* (Grote and Robinson), *S. scitula,* are known to emerge between 6:00 to 10:00 P.M; however, most emergence occurs from 8:30 to 9:00 A.M. on bright sunny days (Becker, 1971). Understanding these emergence patterns allows for better interpretation of their lifecycle and a more accurate quantification.

The method used by Slingerland (1898) to time insect emergence involve the calendar method. Arborists routinely use the calendar method for making preventive pesticide applications (Ascerno, 1991). However, the inconsistency due to climatic temperature changes from year to year lead to unreliable predictions of insect emergence.

Forecasting models are based on accumulated temperatures sufficient to support arthropod growth. These temperature accumulations are known as degree-days and have been developed into tools for monitoring landscape pests. A degree-day is defined as:

$$\frac{(\text{Maximum Temperature} + \text{Minimum Temperature})}{2} - \text{Base Temperature} = \text{Daily GDD}$$

For each 24-hour period that the average temperature is one degree above the base temperature, one degree day accumulates and is called a growing degree-day (GDD). Base temperature is critical for calculating degree-days. This value must be determined experimentally, but can be generalized by using 50° F (10°C) as a base temperature. Accumulated GDD can then be used to refine pesticide application timing. Phenology describe precisely-timed, reoccurring biological event that can also be monitored by calculating GDD. Plants and insects are dependent on temperature for maturation and development. By inspecting insect populations within the urban landscape and assessing the growing degree-days, the monitoring technician will develop data that can be used as a tool in predicting insect development.

Researchers have been able to trap and determine more precisely peak flight of *S. exitiosa* by using GDD accumulated totals. In Ohio, Barry et al. (1978) reported that peak flight of *S. exitiosa* occurred after an average of 1,517 accumulated GDD was reached (Johnson and Mayes, 1983). This information can be used as a guide to determine when pest control applications are required and this method has a significant advantage over traditional insect applications based merely on historical data or the calendar method (Herms, 2001).

Another monitoring technique used by IPM scout is visual inspection of plant material for signs of arthropod infestation. These signs may include honeydew, frass, and/or egg cases. Often, these signs are hidden on the underside of leaves. Monitoring devices, like sticky cards, and traps are used to monitor insect activity. Sticky traps typically do not use pheromones, while many other types of traps do. Among these is the use of arthropod semiochemicals (e.g., sexual pheromones) in conjunction with active pest monitoring (Grant, 2002).

Traps have been designed that collect a broad range of pests, and many of these traps are commercially available. Both the color and design of traps can influence the rate and capture of arthropod species. Baited traps painted white and yellow were attractive to bumblebees but were less attractive than green traps to Japanese beetles (Hamilton et al., 1971). The standard, multi-colored bucket trap, which consists of a forest green canopy, yellow funnel, white bucket and single wire pheromone holder, captured 6.7 times more male velvetbean caterpillars, *Anticarsia gemmatalis* (Hubner) than standard forest green bucket traps (Mitchell et al., 1989). In a separate study, the standard trap also captured significantly more male fall armyworm, *Spodoptera frugiperda* (J.E. Smith) moths than the forest green bucket traps (Mitchell et al., 1989). In contrast, darker black, brown, or green colored traps attracted more day-flying male clearwing moths than white traps (Timmons and Potter, 1981). Trap design affects the shape and size of the pheromone "plume" or wind-borne trail. The direction and behavior of male moths toward the pheromone source was changed in response to altered plumes (Lewis and Macaulay, 1976). Finally, efficiency varies with respect to trap location, height and spacing (Hummel and Miller, 1984). While the correct choice of color will not overcome a poor trap design (e.g., too small of an entrance), the wrong choice of color can render a well-designed trap virtually useless (Mitchell and Heath, 1986).

Aesthetic Injury Level

After inspecting the unhealthy plant, the most fundamental decision to be made is the method of control. One major obstacle to IPM is the lack of clearly defined decision-making rules (Potter, 1986; Pedigo et.al., 1986). Historically, economic factors were not the primary reason for treatment in a landscape.

It was for these non-economic situations that Olkowski (1974) suggested the use of an Aesthetic Injury Level (AIL) to form the basis for pest control decisions. AIL was considered to be the lowest level of a pest damage that caused aesthetic injury. The suggested aesthetic action threshold is the pest density at which control measures must be initiated to prevent reaching the aesthetic damage threshold (Olkowski, 1974; Raupp et al., 1992). An example of AIL is the unsightly damage caused by cypress tip moth *Argyresthia cupressell* (I) increases as a simple linear function of tip-miner abundance (Koehler & Moore, 1983).

Therefore, the decision to implement a control strategy/ tactic is then guided by qualitative factors including density and damage potential of the pest, the use of the plant in the landscape (focal point, key plant), the presence of biological control, alternative control, climatic factors, homeowner input and the landscape company's management policy. While all of these factors help to determine an appropriate control decision, a subjective decision based on the customer's aesthetic tolerance levels may be required (Raupp, 2001). In summary, once the aesthetic injury level and aesthetic action threshold have been determined, the IPM scout must decide which control tactics should be implemented. The decision process must be based on economic, environmental and sociological consequences of their actions.

Clearwing Borers: Sesiidae

Butterflies and moths comprise the insect order Lepidoptera. Worldwide, there are approximately 112,000 different species; roughly 11,000 species are found throughout the United States and Canada (Borror et al., 1989). Within the insect order Lepidoptera, the clearwing moths (Sesiidae) are borers of plants and are composed worldwide of approximately 170 genera with over 1,000 described species. Within this family in North America, more than 151 species of moths belonging to 19 genera are found. Clearwings moths are significant pests of the urban forests; where they attack at least 40 genera of trees, shrubs, vines, and herbaceous plant material in North America (Taft et al., 1991). Clearwing moths range in size from small to fairly large moths. Adult Sesiidae often resemble a wasp in appearance and behavior and are swift daytime flyers. Their forewings are long and narrow and range in length from about 5 to 30 mm. The abdomen is generally elongated, tapers posteriorly, and often narrows at base. The anal tuft is well developed on males and slightly reduced and brush-like on females. Often times various color banding with either white, yellow, orange, red are distributed along the abdomen.

Key characteristics of taxonomic importance that help to identify moths of the Sesiidae include:

1. Basic form of the antennae (setiform or clubbed),
2. Antennal setae "comblike" or pectination "bristlelike,"
3. Scaling of the labial palpi,
4. Wing venation and discal markings,
5. Male/female genitalia,
6. Size and position of clasper plates for the anal tuft (Naumann, 1971),
7. Abdominal segments are at times variously banded and for taxonomic clarification are numbered 1-8 for identification purpose (Taft et al., 1991).

Landscape managers often overlook clearwing borers as pests because many of the symptoms of borer damage can be confused with other biotic and abiotic plant stresses and injuries (Childers et al., 1979). Clearwing borer larvae tunnel beneath the bark and into the vascular tissue of plants. The ravages of larvae occur under bark of trunks, under bark at base of trunk or main roots, in solid wood of trunks, in solid wood at base of trunks and roots, and boring into stems, and roots of shrubs (Fig. 1.1). This penetration can cause branch dieback, loss of vigor, complete girdling, and eventual death to plants. Generally, most trees that suffer from borer infestation exhibit a progressive decline in vigor. Insect galleries or tunnels enhance plant wilting by restricting the flow of water from roots to leaves. This suggests that both the downward transport of photosynthate from leaves and the upward transport of nitrogenous compounds and minerals from the root system are inhibited. This inhibition can lead to death of terminal plant shoots, which may subsequently be followed by decline of one or more lateral branches (Heichel and Turner, 1973). The eventual death of infested trees is most often caused by secondary pathogens, insects, or other biotic and abiotic factors.

Sexual Communication in Clearwing Moths

Effective management of clearwing moth populations to limit economic losses requires population counts, monitoring flight emergence, and geographic location of population outbreaks. Fortunately, clearwing moths are readily attracted to traps baited with synthetic blends of their sexual pheromones.

Attraction to sexual pheromones is achieved primarily by olfaction cues. Short-range visual cues contribute to orientation and mating by male clearwing moths. Visual cues, including color, provide an important role in short-range mate location as males approach a sexual pheromone source (Hummel and Miller, 1984; Childers et al., 1979).

Different species of clearwing moths are known to prefer slightly different pheromone chemical mixtures and ratios in their long-range mating attraction. For example, there is considerable confusion regarding sex pheromone of dogwood borer. Nielsen et al. (1975; 1979) showed that (Z,Z)-3,13-ODDA compound attracted male dogwood borer. However, when improperly manufactured or when small amounts of other isomers such as E,Z-3,13-ODDA are added to compounds, the lure produces inhibitory effects on *S. scitula*. As a result, sex attractant studies in preferred host habitats have yielded inconclusive results and conclusions. However, it appears that (Z,Z)-3,13- ODDA is the chemistry of choice for trapping dogwood borer (Karandinos et al., 1977; Bergh and Leskey 2003).

Identification of the Sexual Pheromones of Sesiid Moths

In the early 1970, the sexual attractants of some economically important clearwing moths (i.e., *S. pictipes, S. exitiosa*) were discovered. Tumlinson et al. (1974) initially isolated the first Sesiidae sex pheromones reporting Z,Z-and E,Z-3,13-octadecadien-1-ol acetate (ODDA) that would capture *S. exitiosa* and *Synanthedon. pictipes* (Snow et al., 1985.) After further investigation, different E,E- , Z,E- , EZ- , and Z,Z-isomers of 3,13-octadecadienyl acetate (E,E-A, Z,E-A, E,Z-A, Z,Z-A) and/or corresponding alcohols (E,Z-OH and Z,Z-OH) were formulated to determine which blends were most effective in capturing not only *S. scitula* but also other *Synanthedon* species. The organic chemistry Z,Z-A 99% Z,Z-A, Z,Z-A, Z,Z-OH, Z,Z-A, E,Z-OH was successful in capturing *S. scitula* (Snow et al., 1985). Regardless of these findings, consistent capture of *S. scitula* remains an elusive goal for entomologists in the field.

Much remains to be learned about the life history, behavior, and ecology of dogwood borer (Bergh and Leskey, 2003).

Since then, the discovery of the Z,E- and E,E-isomers and E,Z and Z,Z-3,13 octadecadien-1-ol were synthesized. Subsequently in 1976, studies were conducted using all four isomers (Z,Z-, E,Z-, Z,E-, E,E) of 3,13-ODDA and all possible double, triple, and quadruple combinations of isomers (Greenfield and Karandinos, 1979). This discovery allowed entomologists to study sexual attraction of numerous clearwing moth species that are attracted to the same or similar pheromones.

In similar studies, Z,Z-exhibited the greatest latitude of attractiveness. Of the 22 clearwing species collected in Byron, GA, 18 were attracted to either Z,Z- or in combination. Combinations of E,E-, Z,E-, and the combination of E,E-,Z,E isomers were not attractive to any species. However, it was shown that E,Z- is attractive only to the lesser peachtree borer. (Snow et al., 1985). In a separate study, three different species were captured using Z,Z, *S. exitiosa*, *S. scitula*, and *Podosesia syringae* (Harris).

Dogwood Borer, *Synanthedon scitula* (Harris)

The geographical range of the dogwood borer, native to North America, extends from southeastern Canada to Florida and west to the Mississippi River. *S. scitula* has the broadest host range of the clearwing moths. The preferred host of *S. scitula* is flowering dogwood, *Cornus florida* (L.) (Taft et al., 1991). Initially, *S. scitula* was a noted pest of the pecan, *Carya illinoensis* (Wang.), K. Koch as early as 1904. *S. scitula* has been commonly referred to pecan tree borer, pecan sesia, ninebark borer, and woody gall borer. *S. scitula* frequently inhabits various insect-induced galls, including galls created by oak gall wasp, *Callirhytis cornigera,* on pin oaks, *Quercus palustris* (Muenchh) and willow oaks, *Q. phellos* (L.). Horned oak galls have proven to be a nutrient rich resource for *S. scitula.* In 1999, dogwood borers were recovered from approximately 15% of the 2-to 3-year old succulent twig galls that were evaluated. In larger galls, as many as four borer larvae were found. Because heavily galled pin oaks may have hundreds of susceptible galls, the possibility that these adult borers from the infested galls may infect other economically valuable trees is important (Eliason and Potter, 2001).

The dogwood borer was first detected in June 1931 in Virginia in June 1931 on 15 to 19% of older on *Cornus florida* nursery stock. According to Engelhardt, overtime, *S. scitula* habits changed, no longer preferring galls and other malformations, but preferring bark and cambium layer of trees (Underhill, 1935). Besides the dogwood, *S. scitula* is considered an economically important pest of many ornamental fruit and nut trees (i.e., beech, birch, hickory, oak, pecan, cherry, mountain ash, willow) and an indirect pest of the apple tree, *Malus domestica* (L.) (Pfeiffer and Killian, 1999; Bergh and Leskey, 2003). In particular, burr knots on apple appear to be a preferred ovipositor site for the dogwood borer. However, infestations do occur in wounds, pruning cuts, and crotches on the branches and trunk.

The physical characteristics of *S. scitula* have often been confused with *Synanthedon pyri* (Harris) is commonly referred to as the apple bark borer. Both borers mine under bark of trunks and in branches. Their larvae, pupal exuvia, and adults are similar in appearance. However, *S. pyri* can be distinguished from *S. scitula* by the presence of a distinct orange discal mark on wings and a wedge-shaped anal tuft. Additionally, their legs are largely yellow, the thorax has a yellow stripe on each side, and the female has the fourth segment wholly yellow above and below. *S. scitula* and *S. pyri* may further be discriminated by their attraction to pheromone blend attraction. Research has shown these two species are attracted to different sex pheromone compounds. *S. pyri* is attracted to E,Z 2,13, Z,Z 99:1 or isometric blend, whereas for *S. scitula,* a Z,Z-3,13-ODDA (Taft et al., 1991; Bergh and Lesky, 2003).

Unlike many Sesiiade, the sexes of *S. scitula* are monomorphic. Gender of *S. scitula* can only be discerned by certain minor markings (Pless, and Stanley, 1967). The head and antennae of males are black, palpi are yellow, and the tips of the antenna are black. In both genders the thorax is deep blue and marked dorso-laterally with a yellow line on each side. The thorax of both genders also has a ventral yellow patch. In males, the dark abdomen is ringed with yellow bands on the second and fourth dorsal segments. In females, segments five and six are yellow ventrally. The forewings are yellow between the veins and the anal tuft is yellow at the sides. The palpi are completely yellow in the female. The legs with forecoxae pale yellow; femora brown black; tibiae mostly yellow, hind tibia with brown black basally and between spurs; tarsi yellow, may be mixed with some brown-black margins. The wing span of both males and females are between 18-22 mm (Beutenmuller, 1901; Pless and Stanley, 1967; Eichlin and Duckworth, 1988.)

The emergence and lifespan of dogwood borer adults varies due to variations in temperature and geographical region. Dogwood borer adults are day-flying clearwing moths that have a prolonged, bimodal seasonal flight pattern. Dogwood borer larvae feed beneath the bark in the phloem and cambial host plant tissues. Small trees may succumb to girdling by a single larva in only one year. Typically over time, the larvae will girdle and kill branches or whole trees over a period of several years (Pless and Stanley, 1967; Heichel and Turner, 1973.) Underhill (1935) reported that in Virginia the period of emergence of *S. scitula* was from the middle of May until the last of September. In Tennessee, *S. scitula* exhibited a bimodal pattern of emergence. The first peak was observed in mid-May and the second occurred in early August and continued through October (Rogers and Grant 1991, and Pless and Stanley, 1967). In Kentucky, *S. scitula* was observed from May to October (Potter and Timmons, 1983.)

Underhill's (1935) account of *S. scitula* reported an average adult life span of 9 days for females and 7 days for males. Adult females deposit eggs in broken bark, usually near wounds. The eggs, which are elliptical and blunt on both ends, generally are deposited singly. In about 20 days the eggs hatch. However, during the latter part of the season as temperatures rise, the egg requires only 8 days to mature and eclose (Underhill, 1935). Larvae of *S. scitula* are off-white to cream-colored with a reddish-brown head. There are 6 larval instars and at maturity is 15-mm long. Pellets of frass, which are pushed out of the larval galleries, indicate the presence of larvae. When development is complete, larvae construct a cocoon and pupate. Pupation generally lasts 15 to 28 days. After emergence a small brown pupal exuviae may be seen protruding from the outer bark (Pless and Stanley, 1967; Solomon, 1995.)

Damage caused by *Synanthedon scitula*

Heichel and Turner (1973) compared the physiological responses of two 15 year-old dogwood trees to the larva of *S. scitula*. The dogwood borer infested one tree and the second tree appeared to be healthy. Stomatal resistances were measured with a ventilated diffusion porometer, which measured the resistance of the epidermis to water vapor diffusion between the interior of the leaf and the atmosphere (Heichel and Turner, 1973.) The stomatal resistance of infested trees, measured on 24 different leaves on each tree, was more than double that of the healthy trees. Higher stomatal resistances in the infested tree grown in the light were attributed to partial closure of the stomata. Heichel and Turner (1973) hypothesized that partial stomata closure and pronounced curling of the leaves on the infested tree suggested a water deficiency. However, they went on to state that the study could not prove that the larval galleries were responsible for the restriction of water flow because only 2 infested trees were studied. While examining the trees he did detect physiological changes in leaf morphology, reduced leaf size, and earlier senescence in the clearwing borer infested tree versus the healthy one. While this study provides valuable insight into physiological plant responses it is not statistically valid because the study did not include enough treatments.

Lilac Borer, *Podosesia syringae* (Harris)

Adult lilac borer, closely mimics *Polistes* spp.,a paper wasps. *P. syringae* are found to infest lilac Syringae spp. (L.), ash *Fraxinus pennsylvanica* (Vahl), privet *Ligustrum* (L.), dogwood *Cornus florida* (L.), apples, oaks *Quercus* spp., and sometimes other oleaceous hosts (Purrington and Nielsen, 1977; Eliason and Potter, 2000).

Color variation and polyphagy have caused confusion in classifying *P. syringae* due to its similarities to the banded ash borer, *Podosesia aureocincta* (Purington and Nielsen 1977) and *P. syringae* are similar morphologically and behave very much alike. However, they are reproductively separated sibling species.*P. aureocincta* emerges late-season which distinguishes it from *P. syringae* (Solomon, 1995). Initially, *P. syringae* was described as *Aegeria syringae* (Harris) and *P. syringae* from *Fraxinus* spp. was described as *Trochilium fraxini* (Lugger). *A. syringae* was renamed *Podosesia* in 1879 and *T. fraxini* was classified into the same genus in 1894 (Beutenmuller, 1901). Instead of classifying these two similar species within a subspecies, Duckworth advised keeping the systematic identity separate (Duckworth and Eichlin, 1977; Solomon, 1975).

The distribution of *P. syringae* occurs from Canada and south over much of the eastern half of the continental United States. The flight emergence of lilac borer adults is initiated at different times depending upon seasonal geographical variation. Emergence periods have been recorded in different geographical areas including: April-June in Illinois, April-May in New England region, June-August in Ohio, May-July in Canada and May-June in Tennessee. In central Florida, adult lilac borer are active during early November (Rodgers and Grant, 1991; Solomon, 1975).

The physical characteristics of *P. syringae* include opaque forewings and dull black hind-wings. Fully extended wings are from 28 - 35 mm (1.1 to 1.38 in) long in females to 24 - 32 mm (0.9 to 1.26 in) long in males (Solomon, 1975). The head is dark brown with a reddish posterior fringe neck and the legs are marked with black and orange bands. Distinguishing features are the hindlegs, which are noticeably longer than the middle and forelegs (Fig. 1.2). This feature makes this species appear to look like a wasp (Solomon, 1995).

Mating behavior at which females initiate calling may depend on temperature during pupal development. Females usually mate soon after emergence. Generally, once the female initiates calling, she tilts her head back and thrusts her abdomen forward while calling out to the males. Mating activities normally occur at 21°C (70° F) and between the hours of 10:00 AM and 12:30 AM. Normally, the females deposit eggs within an hour after mating.

Eggs are light brown, elliptical and measure 0.8 mm (0.03 in) long and 0.4 mm (0.016 in) wide. The outer surface of the egg is finely reticulated. The eggs are deposited singly or in small clusters near bark ridges and in cracks and crevices. On average, 395 eggs are deposited (Solomon, 1975). Eggs generally incubate for 9 to 13 days, and adults live, on average, 5.5 days (Solomon, 1995).

Once hatched, the larva is white except for amber coloring of the head, thoracic shield, and spiracles. The overwintering larva is fully developed with an average head capsule width 2.9 +/- 0.23 mm (0.11 in) (n =13). Prior to pupation, the larval gallery continues almost to the bark surface where a protective paper-thin covering of bark separates the pupa from the outside elements. The pupal stage lasts approximately 3 weeks, and the adults exit from a 4-5 mm (0.16 – 0.2 in) circular hole (Nielsen and Purrington 1978; Solomon, 1975).

The first evidence of larval invasion is an irregularly shaped tiny entrance hole. Feeding activity becomes apparent as frass and sap emerge from the entry site. The gallery created by young feeding larvae is 1-3 cm (0.4 to 0.12 in) wide laterally and 2-5 cm (0.08 to 0.2 in) wide vertically, penetrating into both the phloem and cambium layer. While infestation usually occurs in the lower trunk, it also can occur in branches.

Evidence suggests that insect attack increases as tree diameter increases. Eighteen green ash saplings with a mean butt diameter of 50.8 mm (2 inches) had an average of 0.28 larval mines. In comparison, 11 trees having a mean butt diameter of 185.4 mm (7.3 inches) had an average of 3.45 larval mines (Roberts, 1956).

Sex Pheromone Blends

An effective trap bait for collecting *P. syringae* is isomerically pure (Z,Z-3,13-octadecadien-1-ol acetate [(Z,Z)-ODDA. Although *P. syringae* and *P. aureocincta* are closely related, they respond differently to this isomeric compound. Male *P. syringae* prefer a pure compound, but respond to isomeric mixtures. In contrast, *P. aureocincta* apparently are not attracted to pure Z,Z-3-13–octadecadien-1-ol acetate and require isomeric mixtures for sexual attraction (Purrington and Nielsen, 1977).

Damage caused by *Synantheon syringae*

Within Sesiidae species, *P. syringae* and *P. aureocincta* are known to selectively infest the green ash tree *Fraxinus pennsylvanica* (Vahl) across most of North America. The observed choice of food-plants of *P. syringae* is the solid wood trunks of ash (Beutenmuller, 1900). For hardwood lumber industry to demand a high price, logs must yield a high percentage of pieces that are virtually free of larval blemishes. Grub holes are not acceptable in baseball bats, tennis racquets and tool handles. The larval insect feeding results in great economic loss (Roberts, 1956).

A survey of several hundred 9 year-old ash trees, from 43 different geographic areas, found borers attacked 81% of the trees (Santamour, 1987). According to Gill, Nielson and Balderson noted that ash production in northeast Ohio was impossible because of clearwing borer damage. Losses in nurseries have been estimated at $5,000 per 0.7 hectare (1.73 acres) per cropping cycle. Additionally, Gill noted Peterson found that 50% of the ash trees in urban environment in the Prairie regions of Canada suffered from borer damage (Gill, 1991).

Peach Tree Borer, *Synanthedon exitiosa* (Say)

Synanthedon exitiosa is one of the most economically significant species in the Sesiidae family. *S. exitiosa* is a pest of the commercial fruit industry impacting peach, plum, nectarine, cherry, apricot, and almond production. It is also a major pest of a number of flowering varieties of the genus *Prunus* (Solomon, 1995).

Synanthedon exitiosa was initially described as *Zygana persica* (Barton) in 1803. However, *Z. persica* was not retained because there was not an accurate description of the species. In 1824, it was classified as *Apis persica* (Thomas) who thought *A. persica* belonged in Hymenoptera. In 1825, a *S. exitiosa* female form was described and characterized as *Paranthrene pepsidiformis* (Hubner). In 1825, Harris called *P. pepsidiformis Aegeria persica* (Barton). Eventually, Harris adopted *S. exitiosa* (Buetenmuller, 1901).

A native of the United States the peachtree borer is found in most peach growing areas of the country and variability of flight is contingent upon geographically region and local climate (Solomon 1995). Singerland (1898), stated:

> "The moths begin to appear early in May in the latitude of Washington, D.C. and southward, over what approximates the lower southern region; in the Gulf strip of this region they are recorded as

appearing a month earlier. In the upper austral region, roughly comprising the States above the cotton belt and below the northern tier, the moths do not usually appear until after the middle of June; in the southern portions of some of the states in this region they are recorded as appearing in May. In the northern transition region, which comprises the northern tier of States, together with most of New York and New England, and also including Southern Canada, the moths appear chiefly in July and later, rarely emerging, however, as early as June 15^{th}, and belated individuals as late as October or even November in Canada. June and July are the worst months for the moths over the principal peach districts south of the fortieth degree of latitude, while north of this the moths are the most numerous during July and August, and in Canada from August 15^{th} to September 15^{th} (Buetenmuller, 1901)."

Adult *S. exitiosa* are bluish-black with a wingspan of 27 to 28 mm (1.06 to 1.10 in) and body length of 17 to 23 mm (0.66 to 0.90 in). The body of males is bright, steel blue with a pale yellow to white, narrow band around the abdomen. In females, the front wings, legs, and body, are covered in dark steel-blue scales except for broadband of orange to reddish scales on fourth abdominal segments. There are several subspecies. *S. exitiosa,* including subsp. *edwardsii* which has segment five ringed with orange while subsp. *graefi* has no abdominal banding and is completely brown black. The anal tuft of all *S. exitiosa* is wedge shaped and pale yellow laterally (Fig.1.3) (Eichlin and Duckworth, 1988).

Young *S.. exitiosa* larvae are 1.5 to 1.7 mm (0.05 to 0.06 in) long. At maturity, larvae are 32 to 38 mm (1.2 to 1.49 in) long. The larval body is grayish white with a brown head. During development, larvae appear white-or-cream colored with a dark brown head. The dorsal surface of the prothorax, and the last segment of the abdomen are darkly sclerotized. Inside the composite mixture of frass, larvae usually build cocoons beneath the bark on the trunk or in leaf litter near soil line. Initially, the pupa is white, but eventually changes color to bright brown (Butenmuller, 1901).

The moths begin to mate soon after emergence and typically oviposite the same day. Females ordinarily lay 200 to 800 eggs which are deposited in small groups on the lower 15 cm (5.9 in) of tree trunk. Though they are usually laid directly on the tree, eggs may occasionally be deposited on weeds, grass, debris and bare soil at the base of host plants (Solomon, 1995; Eichlin and Duckworth, 1988). Newly-hatched larval infestations are generally confined to the base of the trunk or root a short distance below the soil surface (Beutenmuller, 1901).

Control Strategies for Managing Clearwing Pest Populations

Several methods are used to manage clearwing moths, (e.g.,biological, mechanical, and applications of chemical pesticides). Biological control is any agent that adversely affects pest species using natural enemies; pathogens, parasitoids and predators to control insect pests. Pathogens could be a bacterium, virus, fungus, protozoan or nematode capable of directly infecting insects by penetrating the chitin, or by ingestion of food material, that eventually kills the pest. A parasitoid is an organism that lives and feeds on another organism and eventually kills it. *Steinernema carpocapsae*, (Weiser, 1955) is a known entomopathogenic nematode that kills clearwing moth larvae. Many insects are vulnerable to entomopathogenic nematodes, such as *Heterorhabrhabditiss* and *Steinernema* spp. By preparing a soil or trunk drench with entomopathogenic nematodes control of certain species of clearwing larvae is possible (Flint and Dreistadt, 1998 and Davidson, Gill, and Raupp, 1992.)

Reducing the damage caused by *P. syringae,* woodpeckers have been considered the most important natural enemy of *P. syringae*. It has been estimated that woodpeckers accounted for elimination of between 67% to 81% of the *P. syringae* (n=357) during 1972 and 1973. Other mortality factors include parasitoids wasp like *Phorocera signata*,(Diptera: Tachinidae) *Apanteles* spp., (Hymenoptera: Braconidae) and *Lissonota* spp.,.(Hymenoptera: Ichneumonidae), as well as fungal disease (e.g., *Beauveria* spp.) (Purrington and Nielsen, 1987).

S. exitiosa has several natural enemies that include the egg parasite *Telenomus quaintancei* (Hymenoptera: Scelionidae) and several larval hymenopteran parasitoids. Other important predators of *S. exitiosa* are field mice, rats, ants, spiders, moles and skunks (Solomon, 1995).

Mechanical control tactics have been utilized to effectively remove clearwing borer larvae. Mechanical control methods involve directly or indirectly destroying larvae or making the environment unsuitable for pest entry (Grant 2002). It has been suggested, for effective control in eliminating *P. syringae* from host plants, that flexible wires, knives (cut and remove), pruning and burning the infested area, and or spraying the trunk with an insecticide can be used (Solomon, 1995).

Another choice in IPM is the use of chemical control. In the past, society has used chemical pesticides as the "silver bullet" for killing targeted pests. Chemical control is an attractive method of control because it is relatively inexpensive, and the initial results are rapid. However, in effective program this should be the last choice in the IPM scouts arsenal of defense. When chemical control is deemed necessary, determination of the feeding behavior of the pest, lifecycles, vulnerability to management tactics, and the mode of action of chemical pesticides must be considered. While there are a number of good chemicals that have low mammalian toxicity and reduce the environmental impact on non-target pests, choosing the right material is vital to maintaining a balanced ecological system and following an integrated IPM landscape management system (Raupp, 2001). Chemical insecticides thoroughly applied to the trunk and branches are effective if the timing is correct. The spray application needs to be applied on the verge of egg hatch and initial entry into the tree. Depending on the target pest two applications may be needed to give season long control (Hale, 2005). In the past arborists used materials such as DDT and dieldrin that had a long residual. These materials were applied in the early spring and the residual remained throughout the larval hatching period. Due to the environmental dangers less persistent insecticides and more environmentally friendly insecticides were developed.

Recently, the Food Quality Protection Act (FQPA) of 1996 amended the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Federal Food, Drug, and Cosmetic Act (FFDCA). These amendments basically changed the way EPA regulated pesticides. Ongoing regulatory and registration changes by the FQPA act are restricting the use of previously useful chemical materials that control clearwing moth larvae. The law mandates a single health standard for all pesticides and periodic reevaluation of pesticide registration (http://www.epa.gov/oppsps1/fqpa/). As a result, several pesticides are being taken off the market. Two effective chemistries Lindane and Dursban that controlled clearwing borer are no longer available. As a result, alternative materials such as Astro are used for control of clearwing borers have shorter residual. Astro's active ingredient is permethrin is used to control *S. pictipes* and other clearwing borer species. The current label rate for Astro is 0.11 to 354 ml. (4 to 12 fl. oz) per 100 gal/A. The advantages of Astro over previous insecticides are increased applicator safety and shorter half life. However, for a borer control product, a shorter half-life is not advantageous (Hale, 2005).

Objectives

The objectives of this research project are 1) determine the color preferences of male Sesiidae moths and to identify the relationship of pheromone trap catch results to male flight activity of *P.syringae* by accumulating season-long (GDD) data, 2) evaluate the effectiveness of three trap colors in combination with four commercially available pheromones, and one experimental blend, 3) identify and clarify the range of clearwing species collected within each commercial blend.

The results of this study are expected to provide a better understanding of the seasonal activity of clearwing moths in eastern Tennessee. In turn, landscape management professionals will gain valuable tools that will increase their precision for timing control strategies, which will limit clearwing pest population growth and subsequent plant damage. Early detection and control of clearwing moths will reduce chemical dependency by properly timing applications and prevent economic and aesthetic injury to the urban landscape.

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Figures

A. Symptoms of feeding by *S. exitiosa*, branch dieback, loss of vigor, complete girdling, and eventual death to plants.

B. Newly hatched larval infestation of *S. exitiosa* is generally confined to the base of the trunk, galls or roots a short distance below the soil surface.

Figure 1.1: Food Habits of Clearwing Borers. *Synanthedon exitiosa* (Say) feeding injury on *Prunus laurocerasus (L.)* cherrylaurel.

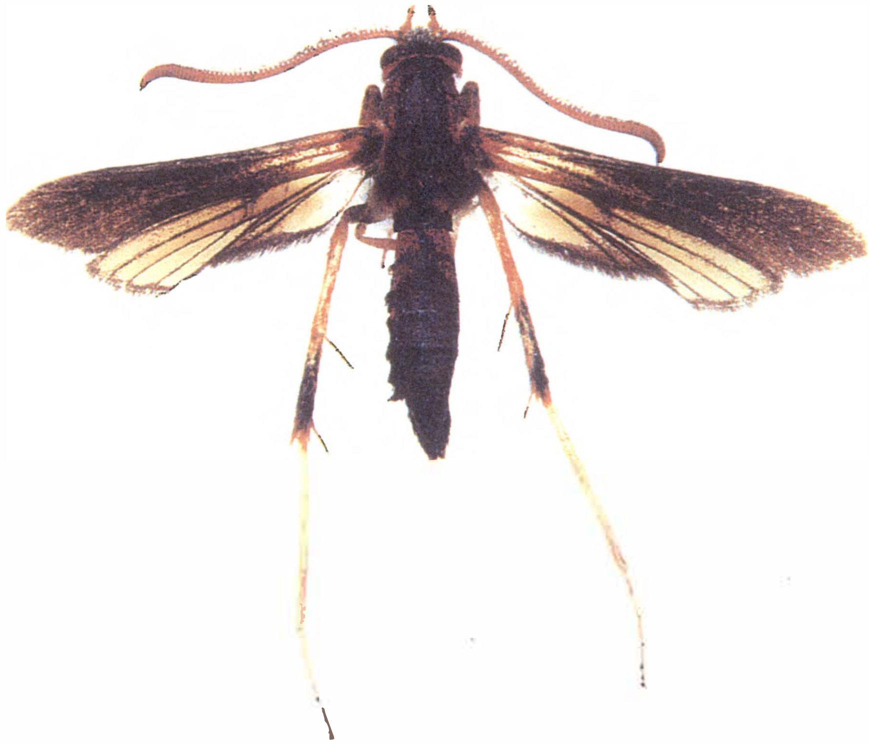

Figure 1.2 Male Lilac Borer, *Podosesia syringae* (Harris)

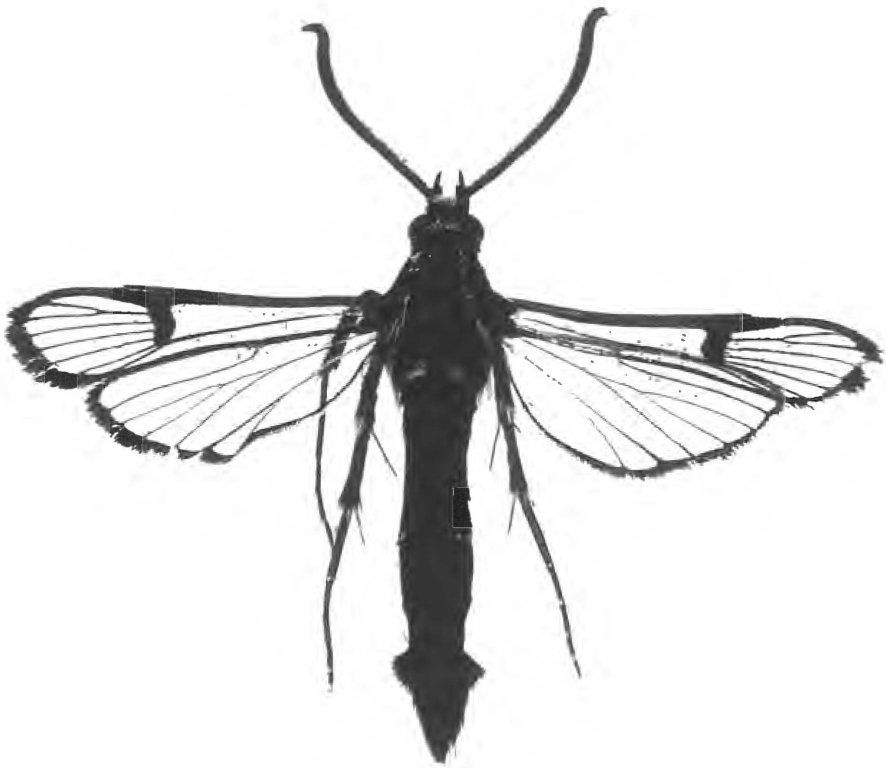

Figure 1.3 Male Peachtree Borer, *Synanthedon exitiosa* (Say)

Part 2: Importance of Color, Brand of Lure and Growing Degree Days to Sesiidae Monitoring

Introduction

Clearwing moths (Lepidoptera: Sesiidae) attack at least 40 plant genera in North America. They are significant pests in urban landscapes and ornamental plant production systems. In North America, clearwing moths are represented by more than 151 species in 19 genera (Taft et al., 1991).

Clearwing moths are swift daytime flyers and difficult to observe. Forewings of sesiid moths are long and narrow. The thorax is often brightly banded, and they mimic wasps (e.g., *Polistes* spp.) in appearance and behavior. Many plant symptoms following borer feeding injury also can be confused with unrelated biotic and abiotic plant stresses. For these reasons, many green industry professionals overlook the clearwing borer as a pest (Raupp et al., 1992).

Different species of clearwing moths utilize slightly different pheromones and varying chemical ratios of pheromone isomers to accomplish long-range mating attraction. Attraction and orientation to pheromones are primarily olfactory responses. Olfactory cues are utilized for long-range attraction, but short-range visual cues also contribute to orientation and mating by the male clearwing (Taft et al., 1991; Bergh and Leskey, 2004).

Research indicates that pheromone trap color affects capture rate of male clearwing moths. Childers et al., (1979), compared various combinations of single trap color (unicolored) and bicolored traps. Black traps caught significantly more males than any other color, while white traps caught the least number of male peachtree borers, *Synanthedon exitiosa* (Say). Timmons and Potter (1981) indicated that dark-colored black, brown, or green traps attracted more male clearwing moths than white traps. In

2002, a preliminary study demonstrated that commercially available, unpainted white and green-topped traps collected more than either black-or-green painted traps (Vaughn and Klingeman, 2002). However, in the study, all traps were not treated equally. The white and green-topped trap was not spray-painted. As a result, the volatiles from the painted traps may have interfered with pheromone plume and confounded test results.

In previous studies, there has been much variability and inconsistency on species specificity of commercially available dogwood borer *Synanthedon scitula* lures. Many target species responded differently to lures marketed for a specific species. The purpose of this research project was to investigate the hypothesis that color and olfactory cues influenced male clearwing trap catch. Paired with bucket-style (e.g., Multipher-1) painted colored traps, commercially available pheromone lures were evaluated for the diversity of clearwing moth species trapped and specifically, their ability to trap the dogwood borer, Synanthedon scitula (Harris). Growing degree-days (GDD) timelines for first flight and accumulated emergence of *S. exitiosa* and *Podosesia syringae* (Harris) were established for East Tennessee. This study summarizes species diversity of clearwing moths attracted to commercially available dogwood borer lures. This study also explorer's clearwing moth preference for colored traps and commercial pheromone blends. These tools are used to forecast emergence and flight activity of clearwing borers.

Materials and Methods

In 2003, five different commercially-available dogwood borer lures were evaluated in 4 East Tennessee locations using Multipher-1 style bucket traps (Great

Lakes IPM, Vestaburg, MI). Multipher-1 style bucket traps are sold commercially and have white plastic bucket traps with a light green top. When charged with Vaportape (10% DDVP) toxicant insecticide tape (Hercon Environmental, Emigsville, PA), clearwing moths are quickly knocked down and die, which preserves the fragile moths for identification. One-third of a piece of Vaportape was placed inside each trap to provide quick knockdown of the fragile male moths.

Multipher-1 traps were lightly sanded and spray-painted using Painters's Touch latex paint (Rust-Oleum, Corp., Vernon Hills, IL) to achieve white, black, and green color treatments. A custom-fabricated (Hodges Machine Shop, Johnson City, TN) triangular metal frame was attached to a steel fencepost at a height of 1.5 m from the ground. Single traps (one of each color treatment) were mounted 50 cm apart on the terminal ends of the triangular frame. The triangular arrangement was expected to allow the greatest likelihood of an even blend of the pheromone plume (Figure 2.1).

Trap layouts were established in a randomized complete block design in four replicated locations. Replicate locations were either maintained (mowed) or unmanaged landscape, which ranged from open grassy fields to deciduous forest transitional ecotones. None of these locations are managed with pesticides for borer control. All locations had several dogwood trees with at least one injured trunk. Each location was about 1.5 acre (0.061 ha) contiguous area. Traps were installed in open areas with unobstructed fields-of-view in Johnson City, Tennessee, at East Tennessee State University, (N 36.30361°, W082.36870°), Tree streets, (N 36.30672°, W82.35652°) Town acres, and N36.33834°, W82.39130), and Milligan College (N36.29883°

W82.29309°). Traps were grouped by brand of lure and each group consisted of three trap-color treatments.

On each stake, the trio of trap colors was charged with one of five brands of commercially available pheromone lures. While all lures were marketed to trap dogwood borers, *S. scitula*, the reported pheromone components and load rates of the commercial brands differed (Table 2.1).

Traps were set approximately two weeks, 14 March, 2003 before the earliest reported emergence of clearwing borers and managed for two weeks after last capture date 17 September 2003. Traps were monitored daily until first reported catch. After the first clearwing moth capture, traps were monitored on three and four day intervals, captured clearwing borers were field identified and tallied. Unrecognized sesiid moths were returned to the laboratory and stored until accurate species identifications could be made. Taxonomic assistance was provided by Dr. Thomas Eichlin, Senior Insect Biosystematist for the State of California Department of Agriculture.

Accumulated GDD data using mean daily temperatures provided for the Tennessee Tri-Cities airport area by the National Weather Service headquarters in Morristown, TN (http://www.srh.noaa.gov). The total numbers of species and counts of individual species captured per trap during the test were compared among lures and locations using PROC GLM of SAS (SAS Institute 1999). Where differences were significant, means were separated using Fisher's Least Significant Difference (LSD) Test at α=0.05.

Results

Color

When clearwing moth trap catch was pooled across species and analyzed by trap color, yield did not differ by location ($F = 2.0$, df=3, 42, $P>0.13$) or color ($F=0.78$, df=2, 42, $P>0.47$) (Table 2.2). There was no interaction of lure and color ($F=0.34$, df=8, 42, $P>0.95$). Then by contrast, there were significant differences in the total numbers of clearwing moths caught, regardless of species trapped, using the different brands of lure ($F=38.38$, df=4,42, $P<0.001$) (Figure 2.2). Each of the brands of lure also yielded a different complex of clearwing species.

Only lilac borers, and peachtree borers, were caught in sufficient numbers to allow statistical comparisons of trap color and brand of lure. Similar numbers of *P. syringae* were caught by location ($F=1.59$, df= 3, 42, $P>0.21$) and color ($F=0.41$, df=2, 42, $P>0.66$). Yet, different numbers of *P. syringae* were trapped depending upon the brand of lure ($F=12.34$, df=4, 42, $P<0.0001$). This indicates a preference among lures (Fig. 2.3). There was no lure with color interaction ($F=2.9$, df=8, 42, $P>0.9$). A second test was conducted to determine the difference between two samples that would result under random sampling with the same mean and variance (LSD = 4.7). Pooled across locations, Scentry lures collected the most male lilac borers.

Similar results were observed for peachtree borers. Neither location ($F=1.75$, df=3, 42, $P>0.17$), color ($F=0.86$, df=2, 42, $P>0.43$), or the interaction of lure with color ($F=0.66$, df=8, 42, $P>0.73$) yielded different trap catch efficiencies. Yet, *S. exitiosa* responded differently to the brands of lure ($F=35.56$, df=4, 42, $P>0.0001$)

and demonstrated a preference for Scentry lures (Figure 2.3).

Growing Degree Days

In 2002 and 2003, seasonal flight activity of adult male lilac borers, and peachtree borers, were compared to local growing degree-day (GDD) accumulations using the base temperature threshold of 50°F (10° C) during the 2002 and 2003 seasons. Dates and associated GDD accumulations began 1 January for forecasting *P. syringae* seasonal activity. GDD are reported as they coincide with first flight catch and 10, 50, and 90% capture of adult male moths (Table 2.3). In both years, lilac borers were first collected April 9 in Johnson City, TN after the accumulation of 107 GDD in 2002 and 165 GDD in 2003. These observations yield a 2-year average of 136 GDD accumulations for borer flight activity (Fig. 2.4). In 2002, the first flight emergence of *P. syringae* also coincided with full flowering of doublefile viburnum, *Viburnum plicatum* (Rehder) (Vaughn, personal observation).

In 2003, peaks in lilac borer trap capture occurred after 539 GDD (May 15 = 133 Julian day), 687 GDD (May 23 = 143 Julian day) and 822 GDD (June 4 = 155 Julian day) (Fig. 2.5). These peaks may be explained by flight activity following cool or cloudy weather rather than emergence of successive generations of borers. During the 2-year study, total capture of *P. syringae* was 1,078 in eastern Tennessee.

Earliest *S. exitiosa* flights were observed following 2-year average accumulations of 1,076 GDD (Table 2.4). Adult borer flight in 2002 began in eastern Tennessee on (May 11 = 131 Julian day) following 602 GDD accumulations. The first flight peak was (June 29 = 180 Julian day) and 1,477 GDD (Figure 2.6). In 2003, the first male peachtree borer flight began and a peak on 2003 (July 1 = Julian day 182) and 1,550 GDD (Figure 2.7). The average 10% accumulated trap catch for two years indicates the approximate target would occur at about date a for protective trunk spray is (June 29 = 180 Julian day).in Johnson City, TN.

Brand of Lure

In 2003, 990 male sesiid moths representing 11 different clearwing borer species were captured using five different commercially available dogwood borer lures. Of 990 moths, only three were male dogwood borers. Similarly, too few moths were captured to enable statistical comparisons among all sesiid species except lilac borers and peachtree borers (Table 2.5). Scentry dogwood borer lures captured the most male sesiid (F=38.38, df=4, 42, P<0.0001, lilac borer males, (F=12.34, df=4, 42 P<0.0001), and peachtree borer males, (F=35.56, df=4, 42, P<0.0001) at all four sites.

Discussion

To establish an optimum management strategy for trapping adult male Sesiid moths, trap color needed to be investigated to determine whether visual color cues play a part in trap efficacy. Dark colored like black, brown, and green traps have been suggested to increase catch success in trapping male sesiid moths in pheromone-baited traps (Childers et al., 1979; Timmons and Potter, 1981). In 2003, collections from uniformly painted traps did not validate our expectation that either black or green traps would yield more male clearwing moths than white traps. Our results may be partly explained if in a linear array of traps placed at 30 cm spacing, the pheromone plume is concentrated at the end of an array aligned, opposite the prevailing wind direction. In the 2003 study, traps were employed a triangular trap arrangement. The triangular arrangement was expected to allow the pheromone plume to be more equally distributed between trap positions regardless of wind direction. This hypothesis was not validated through chemical analysis. Still, contrary to expectation, trap color did not affect trap capture success of adult male clearwing moths. The influence of trap layout on concentration of the pheromone plume, and its potentially confounding effect on moth orientation requires additional research.

Efficacy of commercial dogwood borer lures also continues to be elusive in affecting predicatble pheromone-baited trap yields of male *S. scitula* moths (Davidson et al. 1992; Braxton and Raupp 1995; Bergh and Leskey 2003). In electrophysiological studies, Z,Z-3,13-octadecadien-1-ol acetate (ODDA) elicited strong dogwood borer antennal responses (Nielsen et al. 1979; Bergh et al. 2004). The information provided by manufacturers of five commercially available dogwood borer lures in this study all revealed that the chemistry of each of the lures contained principally (Z,Z)-3,13-ODDA. In this study, neither the lures containing (Z,Z)-3,13-ODDA nor those marketed for capturing dogwood borer were reliable in capturing adult male dogwood borers. According to prior evidence, a reduced olfactory response of dogwood borer males to Z,Z-3-13 -ODDA appears to or “is thought to” occur when small amounts of other isomers or contaminants were incorporated into the manufacturing of the lure (Potter and Tumlinson, 2002 personal communication). The possibility of contaminants in manufacturing, paint volatiles, interaction among the lures themselves and load rates are all expected to contribute to the effectiveness of the lures. Even though lure effectiveness and interaction may confound results, Taft et al. (1991) stated that the pheromone information is useful as general guide in assessing the identity of male clearwing moths.

Seasonal pheromone trap data in 2003 for lilac borers in eastern Tennessee are consistent with previously reported calendar dates of lilac borer emergence and activity (Potter and Timmons 1983 and Rogers and Grant 1991). In Kentucky however, lilac borer flight activity began after average accumulations of 168.9 GDD in Lexington and 189.9 GDD in Louisville (Potter, 1983). Dates of first catch were 5 May 1980, 13 April 1981, and 23 April 1982. By contrast in East Tennessee, first flight catch was 9 April for *P. syringae* in both 2002 (107 GDD) and 2003 (165 GDD). Depending on the number of warm sunny days GDD accumulation could be made up quickly. In 2002, 168 GDD days had accumulated by 13 April.

Sufficient numbers of *S. exitiosa* were captured in both 2002 and 2003 to establish forecasts of flight emergence. However, the emergence and activity of *S. exitiosa* differed for the two years observed in this study. The first peachtree borer was caught on 11 May 2002 (GDD 572) and 1 July 2003 (GDD 1550). The discrepancy between accumulated GDD in 2002 and 2003 and first trap is not readily explained. Growing degree-day accumulations are dependent on weather. Seasonal abundance of cloudy and rainy days reduces accumulated GDD. By 11 May, 2002 the precipitation total was 13.74 in while it was 21.27" by May 11 2003 (http://www.srh.noaa.gov). The lower rainfall totals in May 2002 suggest an explanation for an earlier flight emergence of *S. exitiosa*. Still, prior studies in Tennessee have recorded male peachtree borer flight activity from late-May through mid-September (Rogers and Grant, 1991). Regardless of the date of first flight by *S. exitiosa*, landscape managers must be vigilantto clearwing borer activity from late spring to early fall.

Our analysis of commercially available pheromone lures indicates that dogwood borer males were not reliably attracted to any of the tested products. Lack of attraction to these lures may be attributed experimentally to factors including trap style, volatilization of latex paint, pheromone load rate, interaction of isomer blends, and possible variations in isomer content and purity. Each of these issues, in turn, requires additional testing to obtain the optimum in trapping protocol for these moth species. For example, in certain habitats, large numbers of dogwood borer have been collected when Scenturion lures were used with adhesive-coated wing traps (Bergh et al., 2004). In the 2003 study, too, Mulipher-1 traps were selected to preserve the physical appearance for accurate species identification of captured adult male moths. In this regard, the current study did clarify the identity of alternative sesiids attracted to pheromone lure brands marketed to trap a narrowly stated species range of male clearwing moths.

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Tables

Table 2.1: Phermone Components of Commercially-Available Dogwood Borer Lures Used in 2003 Trials

Brand of Lure	Load Rate	Pheromone Components	Manufacturer
SC-L119 ("Scentry")	12 mg/ml	Z,Z-3,13-octadecadienyl acetate	Scentry, Inc., Billings, MT
L3-4027/000 ("Phero Tech")	250 µg/ml	Z,Z-3,13-octadecadienyl acetate	Phero Tech, Inc, Delta, British Columbia, CAN
DWB Lure ("IPM Tech")	1 mg/ml	Z,Z-3,13-octadecadienyl-1-ol acetate	IPM Tech, Inc., Portland, OR
Scenturion 149 ("Scenturion")	1 mg/ml	100:1 E,Z-2,13-octadecadienyl acetate Z,Z-3,13-octadecadienyl acetate	Suterra LLC, Bend, OR
European Test-Blend ("European")	1 mg/ml	96% Z,Z-3,13-octadecadienyl acetate 4% E,Z-3,13-octadecadienyl acetate small amounts of Z,Z-2,13-18Ac & E,Z-2,13-18Ac	Great Lakes, IPM, Vestaburg, MI

Table 2.2: Influence of Pheromone Trap Color on Sessiidae Collected

Clearwing Species Captured	White	Green	Black
Paranthrene asilipennis (Guérin-Méneville)	2	3	1
Paranthrene palmii (Hy. Edwards)	3	8	6
Paranthrene simulans (Grote)	11	1	5
Podosesia syringae (Harris)	135	165	138
Synanthedon acerni (Clemens)	2	0	2
Synanthedon acerrubri Englehardt	0	0	1
Synanthedon exitiosa (Say)	120	179	175
Synanthedon fatifera Hodges	5	7	10
Synathedon pictipes (Grote & Robinson)	1	0	1
Synanthedon rhododenri (Beutenmuller)	2	3	1
Synanthedon scitula (Harris)	2	1	0
Total (n=990)	**283**	**367**	**340**

Table 2.3: Forecasting Flight Emergence of Lilac Borer, *Podosesia syringae*

	2002			2003		
Catch	**Calendar Date**	**Julian Date**	**GDD**	**Calendar Date**	**Julian Date**	**GDD**
1st	9-April	99	107	9-April	99	165
10%	16-Aprill	106	216	28-April	118	294
50%	1-May	121	415	28-May	148	737
90%	12-Jun	163	1089	26-Jun	177	1395

*GDD trap catch data are pooled across pheromone types and locations to represent accumulations in East Tennessee, 2002-2003

Table 2.4: **Forecasting Flight Emergence of Peachtree Borer, *Synanthedon exitiosa***

	2002			2003		
Catch	**Calendar Date**	**Julian**	**GDD**	**Calendar Date**	**Julian Date**	**GDD**
1st	11-May	131	602	1-Jul	182	1550
10%	18-Jun	169	1267	7-Jul	188	1691
50%	13-Jul	194	1850	27-Jul	208	2203
90%	10-Aug	242	2568	10-Aug	249	2758

*GDD trap catch data are pooled across pheromone types and locations to represent accumulations in East Tennessee, 2002-2003.

Table 2.5: Species Caught by Brand of Pheromone Lure

Pheremone Lure	Scentry	Centurion	European	IPM Tech	PheroTech
Paranthrene asilipennis (Guérin-Méneville)	1	0	5	0	0
Paranthrene palmii (Hy. Edwards)	1	6	7	2	1
Paranthrene simulans (Grote)	9	7	0	1	0
Podosesia syringae (Harris)	202	92	18	78	48
Synanthedon acerni (Clemens)	0	0	3	0	1
Synanthedo acerrubri Englehardt	0	0	1	0	0
Synanthedon exitiosa (Say)	385	64	6	5	14
Synanthedon fatifera Hodges	6	7	0	3	6
Synathedon pictipes (Grote & Robinson)	2	0	0	0	0
Synanthedon rhododendri(Beutenmuller)	0	1	0	3	2
Synanthedon scitula (Harris)	0	1	1	1	0
Total (n=990)	**606**	**178**	**41**	**93**	**72**

Figures

Figure 2.1: One of Four Locations (East Tennessee State University), which Consisted of Three-Color Treatment, Arranged on a Custom-Designed Triangular Frame

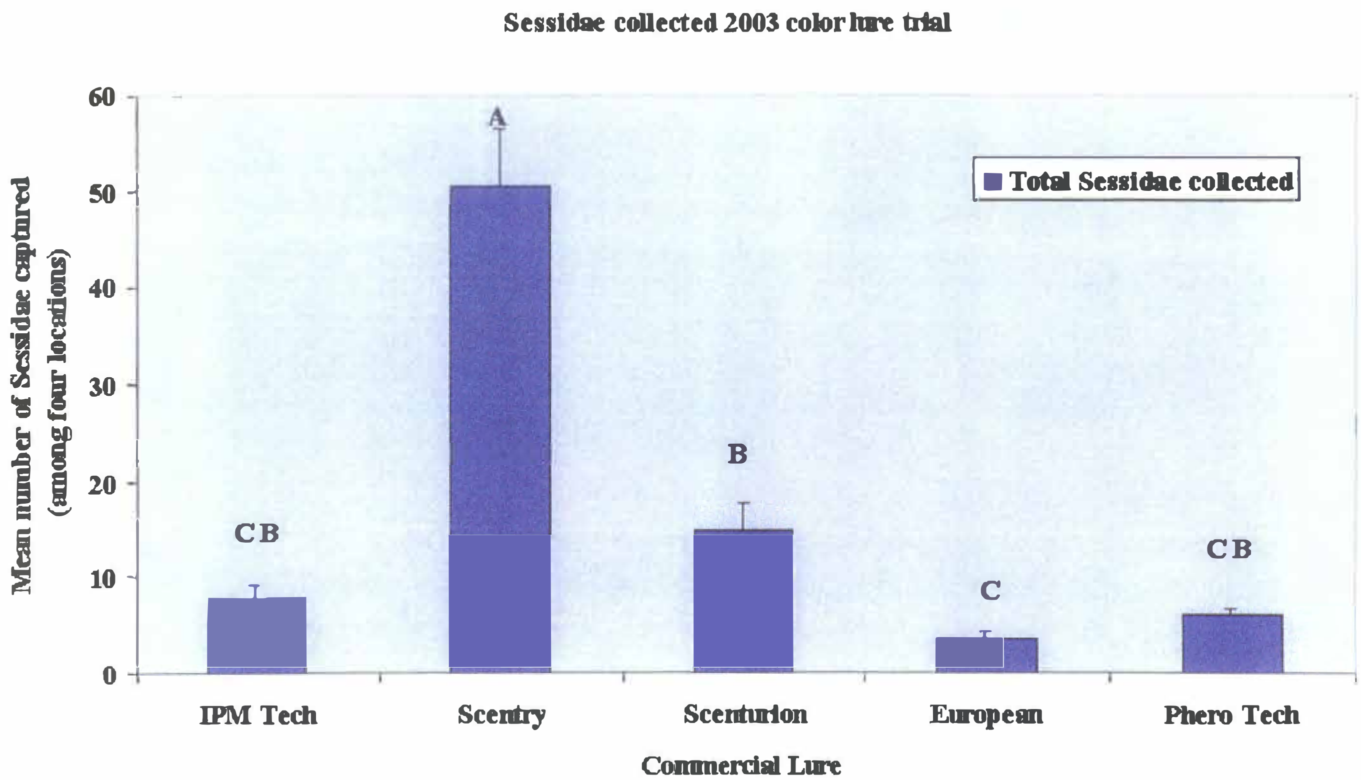

Figure 2.2: Total Adult Male Sesiidae Collected in 2003 Color Test Trapping Study by Lure. Values represent least significant difference (LSD) calculated by the comparisonwise error rate in SAS. Error bars reflect standard error mean. Means with no similar letters are different by LSD separation (*P*=0.05).

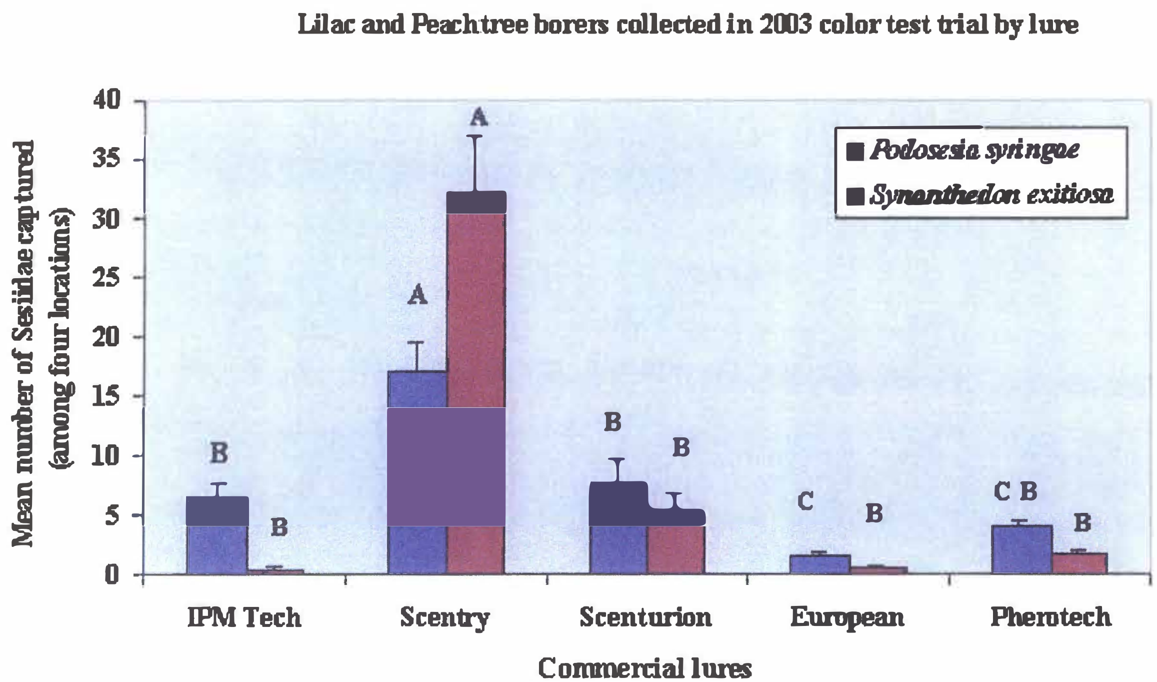

Figure 2.3: Lilac Borers, (*Podosesia syringae*) and Peachtree Borers, (*Synanthedon exitiosa*), Collected in 2003 Color Test Trapping Study by Lure. Values represent least significant difference (LSD) calculated by the comparisonwise error rate in SAS. Error bars reflect standard error mean. Means with no similar letters are different by LSD separation (*P*=0.05).

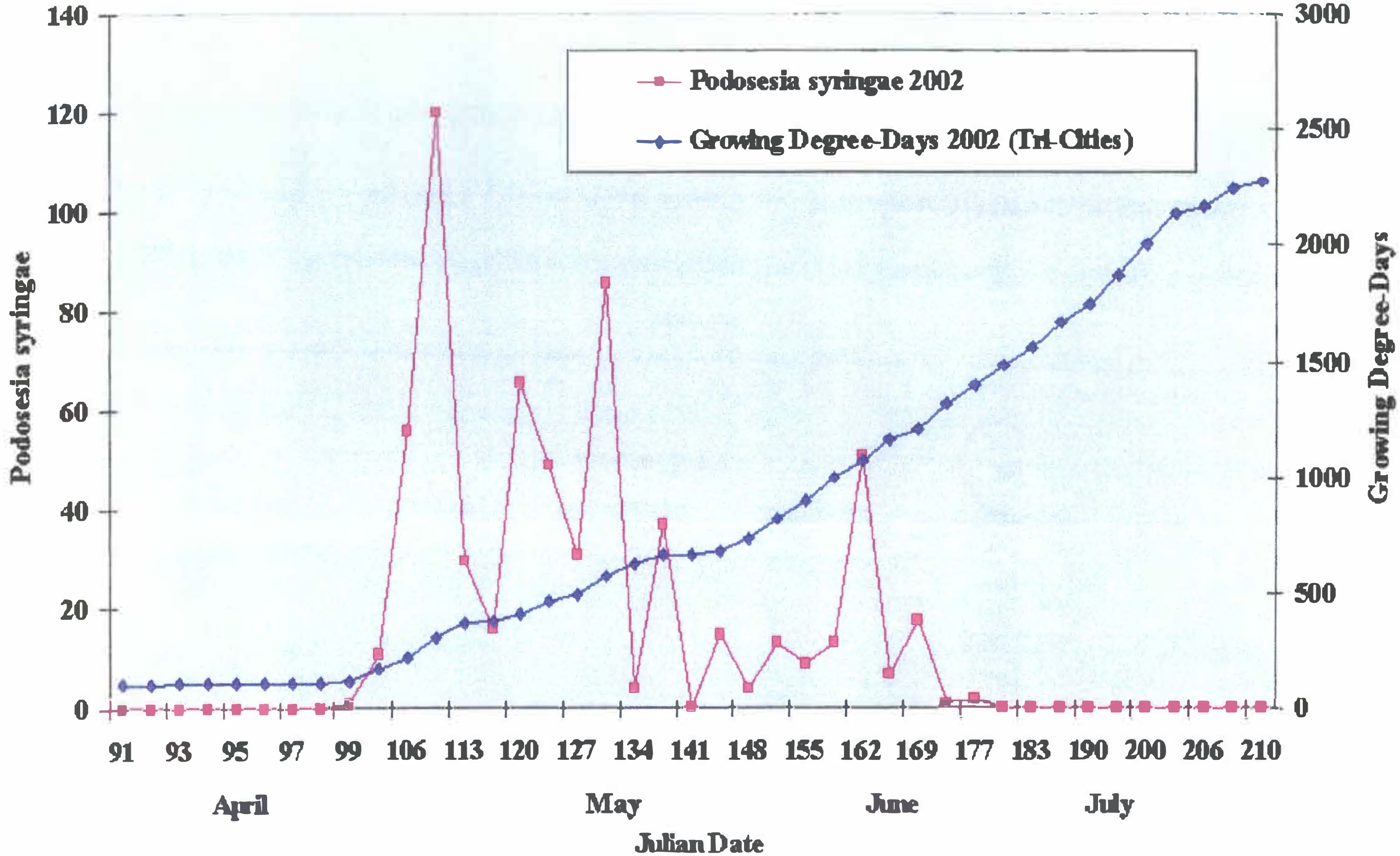

Figure 2.4: Seasonal Occurence of *Podosesia syringae* in Relation to Growing Degree-Days, 2002.

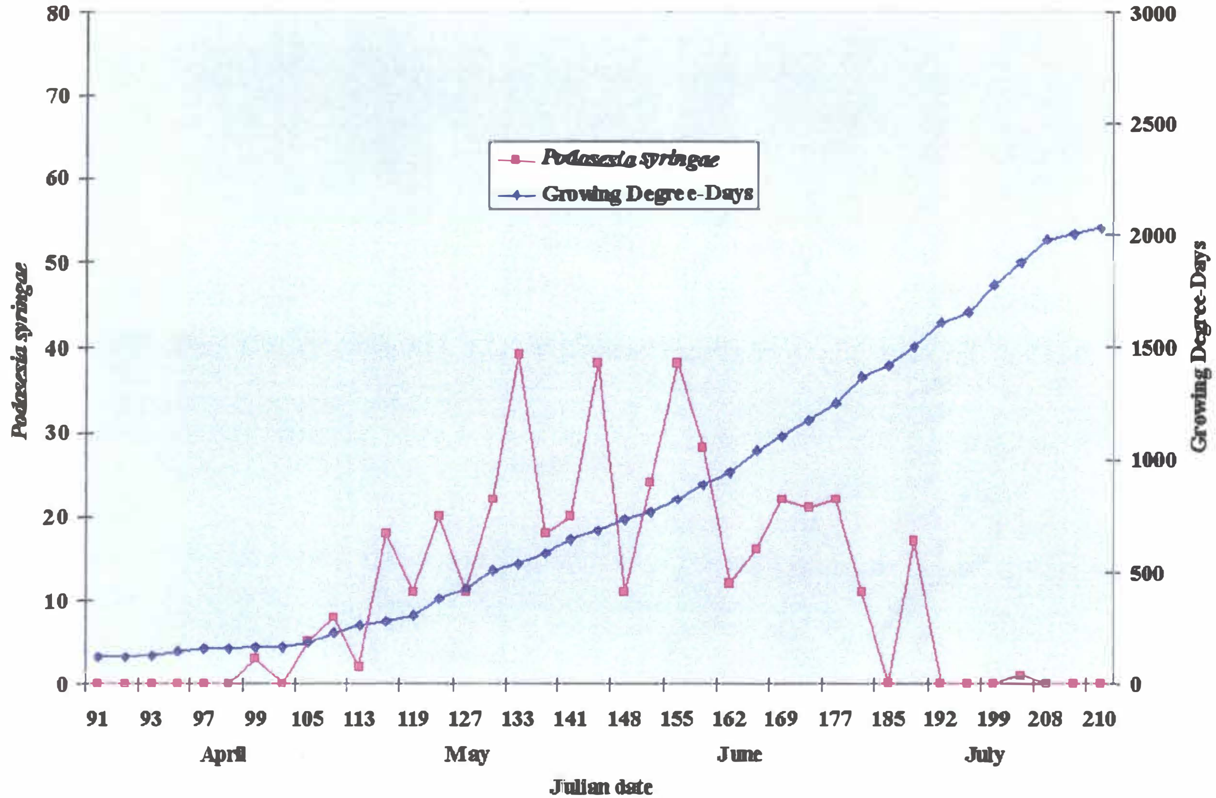

Figure 2.5: Seasonal Occurrence of *Podosesia syringae* in Relation to Growing Degree-Days, 2003.

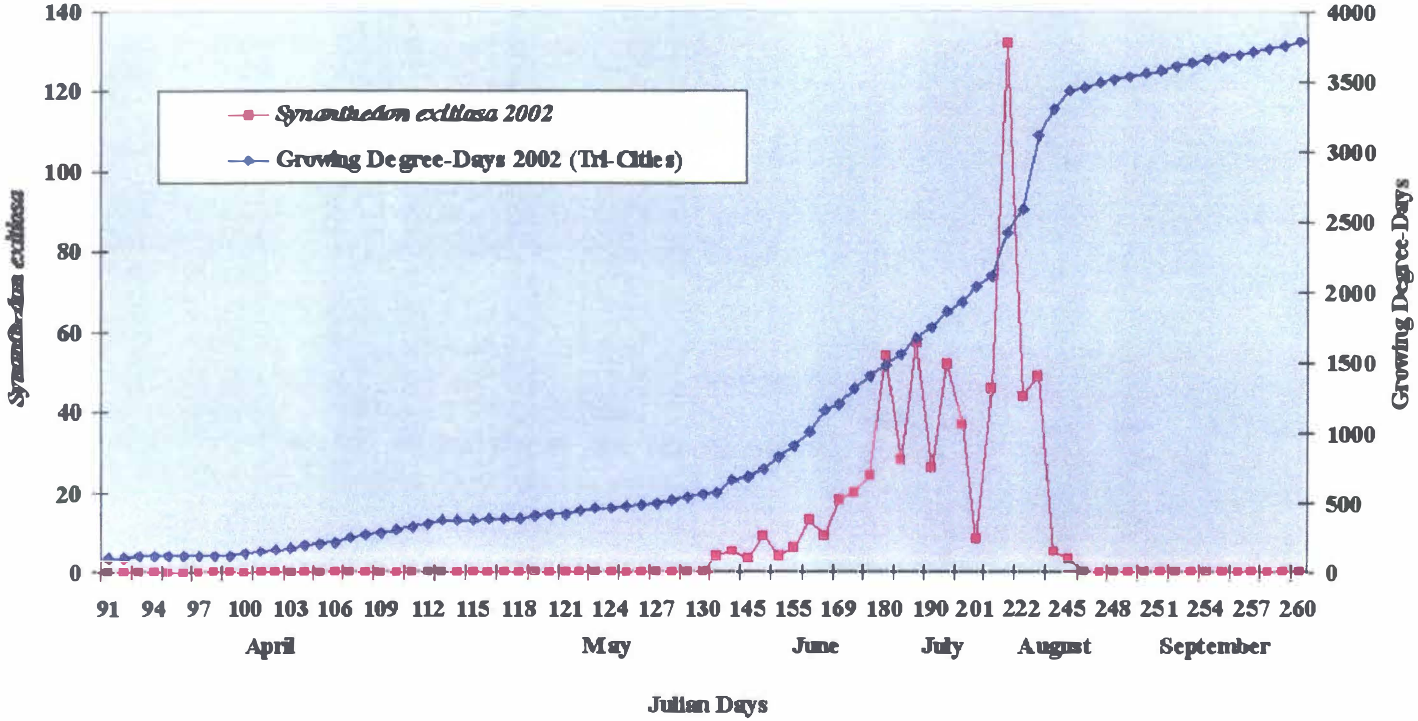

Figure 2.6: Seasonal Occurrence of *Synanthedon exitiosa* in Relation to Growing Degree-Days, 2002.

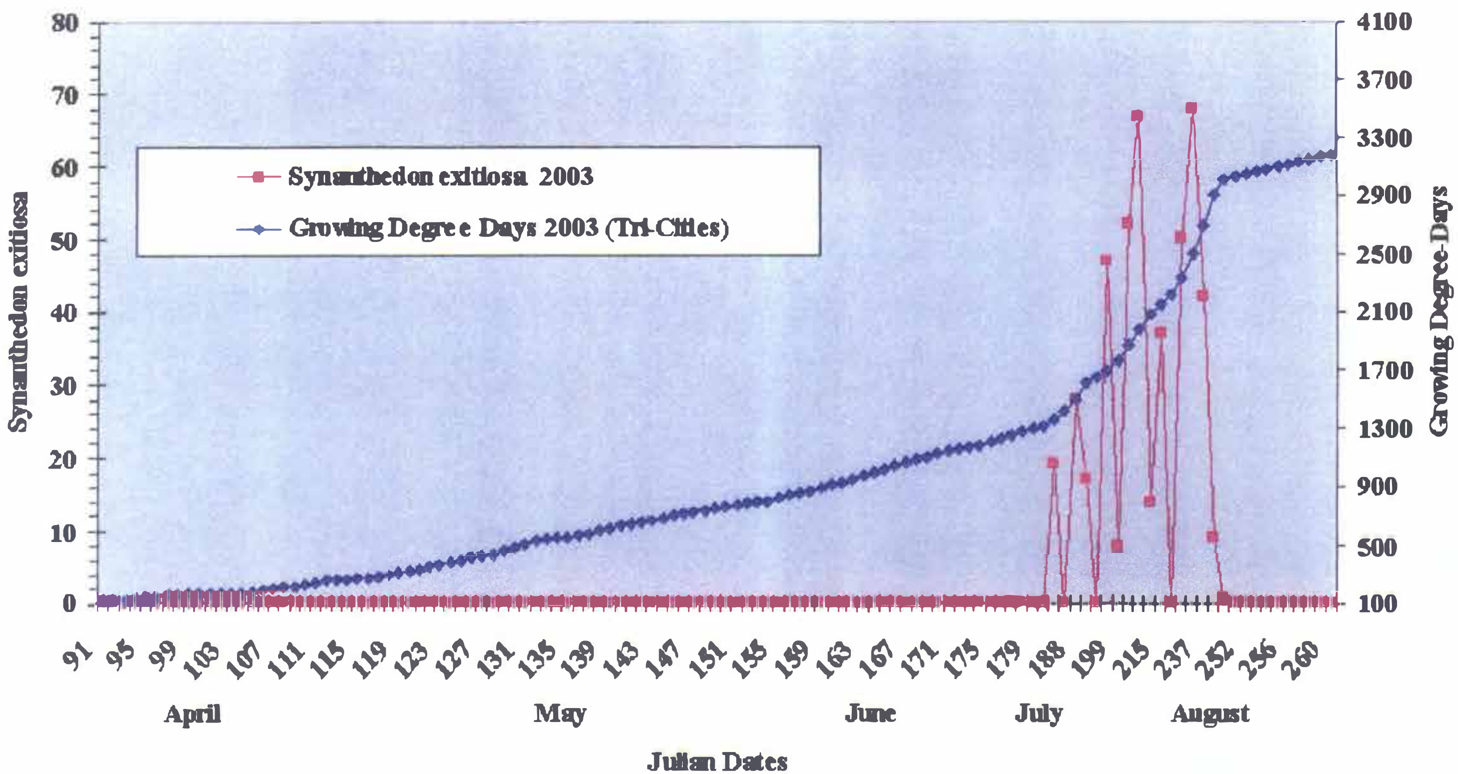

Figure 2.7: Seasonal Occurrence of *Synanthedon exitiosa* in Relation to Growing Degree-Days, 2003.

Part 3: Influence of Brand of Dogwood Borer Lure on Diversity and Number of Clearwing Moths (Lepidoptera: Sesiidae) Captured in East Tennessee

Introduction

The clearwing moths (Lepidoptera: Sesiidae) are representative of a family of over 1,000 described species. Clearwing moths are distributed worldwide except in the most frigid regions of the world. Generally, due to their small size and furtive behavior, adult sesiids are inconspicuous in the landscape. During the last century, Sessidae have been the subject of two extensive monographs (Beutenmuller, 1901; Englehardt, 1946). Our worldwide knowledge of distribution, abundance, and commercially available sex pheromone attraction of the group at the taxonomic level is still poor (Braxton and Raupp, 1995).

In North America north of Mexico, more than 151 clearwing moths are represented by 19 genera.(Taft et al., 1991) Among these, the dogwood borer, *Synanthedon scitula* (Harris) is reported to have the broadest host range of the clearwing moths, though the preferred host of *S. scitula* is flowering dogwood, *Cornus florida* (L.) (Taft et al., 1991). Besides flowering dogwood, *S. scitula* is considered an economically important pest of fruit and nut trees including beech, hickory, oak and pecan, and native and ornamental birch, cherry, mountain ash and willow. The dogwood borer also is an opportunistic pest of the apple tree, *Malus domestica* (L.). While burr knots on apple appear to provide a preferred oviposition site for dogwood borer, infestations also occur in wounds, pruning cuts, and crotches on the branches and trunk of apple trees (Pfeiffer and Killian, 1999; Bergh and Leskey, 2002; Bergh and Leskey, 2003).

Sexual pheromone-based lures have successfully been used for species identification, seasonal monitoring, and mating disruption for many pest insects. Tumlinson and others (1974) isolated the first Sesiidae sex pheromones. They reported that Z, Z-and E, Z-isomers of 3-13-octadecadien-1-ol acetate (ODDA) could be used to reliably capture peachtree borer, *Synanthedon exitios* (Say) and lesser peachtree borer *Synanthedon pictipes* (Grote and Robinson) (Snow et al., 1985). After further investigation, different E,E- Z,E-E, Z-; and Z,Z-isomers of 3,13-octadecadienyl acetate (E,E- A, Z,E- A, E,Z- A, Z,Z- A) or the corresponding alcohol isomers (E,Z-OH and Z,Z-OH) also were formulated. These blends were tested to determine which compositions were most effective in capturing the dogwood borer and also other *Synanthedon* species.

Lures containing pure Z,Z- isomers of 3,13-ODDA have been effective in capturing *S. scitula* (Potter 2002;Tumlinson, 2002 pers. comm.). Commercially-developed lures have been marketed to capture the dogwood borer that contain pure (Z,Z)-3-13-ODDA. Lures baited with other compounds or other isomeric blends are also marketed to capture *S. scitula*, but are often not species specific. Such lures frequently attract males of different non-target and non-pest genera of Sesiidae (Rogers and Grant 1990; Braxton and Raupp 1995). Previous research concluded that several commercially-available pheromone lures used to trap dogwood borer males were not consistently reliable for monitoring seasonal flight activity. Pfeiffer and Killian (1999) reported that rubber septum-type lures, which contained Trécé lilac/ash pheromone used to attract the lilac borer, *Podosesia syringae* (Harris), actually captured more dogwood borers than a lure commercially manufactured by Scentry to trap the dogwood borer. However, Pfeiffer and Killian (1999) acknowledged that results were difficult to explain since both lures were reported to contain Z,Z-isomers of 3,13-ODDA. Bergh et al., (2004) also published a report showing the ineffectiveness of several commercially-available pheromone lures marketed to attract dogwood borer. However, prior research has not documented the species diversity or number of non-target sesiidae collected in seasonal trapping.

For the landscape or grounds maintenance professional contracted to keep plants healthy, pest population monitoring can be a practical and cost-effective way to limit pest damage to valuable trees and shrubs. However, monitoring is only effective if the IPM scout has the proper tools. This research project was undertaken to evaluate the effectiveness of the most commonly used pheromone lures currently marketed to trap or monitor the dogwood borer and to compare this with a potentially novel lure introduced from Europe. The second objective of this work was to obtain seasonal counts, monitor seasonal flight activity, and clarify the identity of non-target sesiidae attracted to lures stated to trap the dogwood borer.

Materials and Methods

In March 2003, a study was initiated at three study sites to evaluate the effectiveness of five commercially-available lures marketed to trap the dogwood borer. Chosen locations were an abandoned apple orchard located in Johnson City, Tennessee (N 36.30582°, W082.25533°), a managed landscape on Austin Springs Road in Johnson City, Tennessee (N 36.34268°, W 082.33197°), and a commercial nursery in Elizabethon, Tennessee (N 36.29887°, W. 082.25533°). At all locations, three replicates of five commercial lures and unbaited control traps were placed within each site in a randomized complete block design. No clearwing moths were caught on any date in unbaited traps. Because of the absence of data, these traps were excluded from statistical comparisons. All of the commercially-available tested lures were red rubber septa impregnated with different load rates of a synthesized pheromone attractant which were reported to be effective for capturing male dogwood borer (Table 3.1). The European test-lure was loaded in a small plastic vial. Traps were unpainted white Multipher –1 style bucket traps with green lids (Great Lakes IPM, Vestaburg, MI). Within replicated blocks, a single trap was mounted on a metal frame constructed by Hodges Machine Shop, Johnson City, Tennessee. The trap frame was secured to a steel fence post at a height of 1.5 meters. Trap stands were spaced three to a linear row and 30 feet apart. Vaportape (10% DDVP) toxicant insecticide tape (Hercon Environmental, Emigsville, PA) was cut in three sections, with one section placed inside each trap to provide quick knockdown of fragile male moths.

Traps were set approximately two weeks before the earliest reported emergence of clearwing borers. Traps were monitored on three and four day intervals from March 2003 thru October 2003. Captured clearwing borers were tallied by species and trap. Initial counts were based on field identification while species identification was conducted in the lab. Growing degree-days were calculated from daily mean temperatures, provided for the Tennessee Tri-Cities Airport area by the National Weather Service headquarters in Morristown, TN (http://www.srh.noaa.gov). For several sesiidae species, samples were submitted to Dr. Thomas Eichlin (Senior Insect Biosystematist, State of California Department of Agriculture). The total numbers of species and counts of individual species captured per trap during the test were compared among lures and locations using PROC GLM of SAS (SAS Institute 1999). Where differences were significant, means were separated using Fisher's Least Significant Difference (LSD) Test at α=0.05.

Results

Brand of Lure

In 2003, 1,121 male sesiid moths were captured using all five commercially-available dogwood borer lures. Lure brands were specifically stated to trap *S. scitula*, yet these pheromone-based lures attracted and enabled the capture of 13 different clearwing borer species. Of the 1,121 moths, only three were dogwood borers (Table 3.1). When clearwing moth trap catch was pooled among species trap yield they did not differ by locations (F=9.93, df=2, 28, P>0.06). There also was no interaction of lure brand across locations (F=1.57, df=8, 28, P>0.18). By contrast, the brands of lure caught different numbers of sesiid moths (F=51.02, df=4, 28, P<0.0001) with the Scentry SC-L119 lure outperforming the others (Figure 3.1)

Only peachtree borers and lilac borers were caught in sufficient numbers at the three locations to allow statistical comparisons of species captured by brand of lure. Similar numbers of peachtree borers were caught at each location (F=0.69, df=2, 28, P>0.51). Lure brands performed similarly at all three locations (F=0.24, df=8, 28, P>0.98).

By contrast, different quantities of *P. syringae* were trapped depending on brand of lure (F=.25.92, df=4, 28, P<0.0001) (Figure 3.2). Statistically, Scentry lures attracted and trapped the greatest number of *S. exitiosa* and *P. syringae (Figure 3.2).*

Lure brands yielded variable results for capturing lilac borer trap capture, (F=21.99, df=4, 28, P<0.0001) (Fig.3.2). Regardless of location and brand of lure, similar numbers of *P. syringae* were trapped (F=2.28, df=8, 28, P>0.051). The number of lilac borers collected differed among locations (F=14.46, df=2, 28, P<0.0001). The commercial nursery captured the largest number of *P. syringae*. We have insufficient evidence to explain the distance that clearwing borer moths males may be attracted to pheromone traps. For this reason, host plant surveys were not conducted at each experimental location and data was not included.

Growing Degree Days

In 2003, seasonal flight activities of adult male lilac borer and peachtree borer were compared to local growing degree-day (GDD) accumulations using generalized base temperature threshold of 50°F (10°C). Lilac borers were first collected on 15 April (105 Julian days) following the accumulation of 181 GDD. The heaviest flight activity was between (30 April = 120 Julian days) following accumulations of 320 GDD and (17 May = 137 Julian days) after 582 GDD (Figure 3.3). The east Tennessee flight period in both 2002 and 2003 is consistent with flight data describing borer emergence in earlier research (Potter and Timmons, 1983).

In 2003, records of seasonal flight activity of adult male peachtree borer were first apparent by trap catch date on (24 May = 144 Julian days) following 687 GDD accumulations. Peachtree borer adults were trapped consistently from (6 June = 169 Julian day) after 1104 GDD and (30 July = Julian 212) (GDD 2049) (Figure 3.4). These dates corresponded with historic calendar flight records for East Tennessee (Rogers and Grant, 1991).

Discussion

Our data and those of previous studies on male dogwood borer show limited reliability in male moth capture using commercially available pheromone lures (Braxton and Raupp, 1995; Bergh and Leskey, 2003; Rogers and Grant, 1990). Of the five commercially available lures tested in eastern Tennessee, only three dogwood borers were captured on Scenturion (n=2) and Phero Tech (n=1) brands of pheromone lures. The 2003 trap data from east Tennessee contributes to prior research reports by expanding knowledge about the diversity of clearwing moth species that are attracted to commercial pheromone lures. This study identifies 14 different species of sesiid moths that were collected using pheromone chemistry that contained Z,Z-isomers of 3,13-ODDA. This pheromone composition is reported to be attractive to the male dogwood borer. While Z,Z-isomers of 3,13-ODDA are believed to be main components in dogwood borer sexual pheromones and a key component in other sesiidae attraction, it is likely *S. scitula* is comprised of additional and unidentified compounds (Bergh et al., 2004). Results of 2003 trapping further indicate a need for additional research and refinement of the chemistries used to elicit male dogwood borer mate-finding behavior (Pfeiffer and Killian 1999; Bergh and Leskey 2004).

Recently, Dr. Aijun Zang, a research chemist with the USDA-ARS in Beltsville, MD, has reanalyzed the female sex pheromone of *S. scitula* and has synthesized a more effective chemical analog. Recent studies have successfully collected dogwood borer using Scenturion lures paired with adhesive-coated wing traps in Virginia and West Virginia apple orchards. The new blends have been compared with Scenturion dogwood borer lure and captured 37 to 47 times more dogwood borer males (Bergh and Leskey, 2004 unpublished data).

During the collection period, *P. syringae* and *S. exitiosa* were trapped in large numbers on Scentry and only a couple with a European test-lure. Researchers have suggested that variations in isomeric blends, content, pheromone release rate, and load rate each can affect trap catch. A typical load rate for commercial pheromone lures was 1 mg/ml (Bergh and Leskey, 2003). In the east Tennessee study, lures load rates were not quantified and pheromone blends were not gas chromotography tested. However, manufacturers described the load rates and the chemical composition of the five lures tested (Table 3.2). Scentry manufactured reported a load rate 12 mg/ml, which was 12 times the rate of typical pheromone lures. Scentry captured 601 of the 1121 total adult clearwing males of 14 different sesiid species. Regardless of load rate, results of 2003 trapping in East Tennessee failed to reliably trap dogwood borers. This may be partially explained if *S. scitula* is capable of exiting the Multipher-1 trap design before the DDVP toxicant takes effect. Previous studies have shown a possible reason for the pheromone lures ineffectiveness might be poor composition and manufacturing of the pheromone (Potter, 2002). Other species were captured only on a specific brand of lure. For example, the test lure from Europe was the only pheromone blend and load rate to trap red maple borer, *Synanthedon acerrubri* (Englehardt) (n=7), oak clearwing moths, *Paranthrene asilipennis* (Guérin-Méneville) (n=2) and nearly all of the maple callus borer, *Synanthedon acerni* (Clemens) (n=24 of n=25). Similarly, the IPM Tech lure was the only brand to capture *Carmenta bassiformis* (Walker) (n=2). The host plants of this sessid moth include ironweed, *vernonia noveboracensis* (L.) and possibly joe-pye-weed, *Eupatorium purpureum* (L.). As these ornamental plant species become more popular among native plant enthusiasts, pheromone lures that trap these moth species may become useful management tools.

Our trapping in East Tennessee elaborates on earlier research by identifying the diversity of sesiid moths attracted to these commercial brands of pheromone lure. This information will aid homeowners and landscape management professionals in selecting lures that help identify and predict seasonal moth emergence and flight activity. Often, closely related species require taxonomic assistance in determining which species were captured. For example, the larvae, pupal exuvia and adults of apple bark borer, *Synanthedon pyri* (Harris), and *S. scitula* are similar in appearance and infest the same sites on apple trees (Woodside 1952; Bergh and Leskey 2003). Recognizing that the adult clearwing *S. pyri* moth has a distinct orange discal mark and wedge-shaped anal tuft may reduce our reliance on expert taxonomic assistance. A need remains to develop a detailed photographic description of species captured. Landscape professionals would find this a useful tool and component of a holistic landscape IPM service. A photographic database of taxonomic observations and species-specific identification would be a helpful addendum to "A Guide to the Clearwing Borers (Sesiidae) of the North Central United States" (Taft et al., 1991) and "The Moths of America north of Mexico"; (Eichlin and Duckworth, 1988).

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Tables

Table 3.1: Clearwing Species Caught by Brand of Pheromone Lure

Pheremone Lure	Scentry	Scenturion	European	IPM Tech	Phero Tech
Carmenta bassiformis (Walker)	0	0	0	2	0
Paranthrene asilipennis (Guérin-Méneville)	0	0	2	0	0
Paranthrene palmii (Hy. Edwards)	2	3	0	0	1
Paranthrene simulans (Grote)	2	1	7	0	1
Podosesia syringae (Harris)	252	127	5	124	93
Podosesia aurenocincta (Purrington & Nielsen)	5	0	1	0	0
Synanthedon acerni (Clemens)	0	0	24	1	0
Synanthedon acerrubri Englehardt	0	0	7	0	0
Synanthedon exitiosa (Say)	323	32	1	20	28
Synanthedon fatifera Hodges	12	6	1	13	3
Synanthedon rhododendri (Beutenmuller)	1	4	0	6	2
Synanthedon scitula (Harris)	0	2	0	0	1
Vitacea polistiformis (Harris)	1	0	4	0	0
Vitacea scepsiformis (Hy. Edwards)	1	0	0	0	0
Total (n=1121)	**599**	**175**	**52**	**166**	**129**
Species (n=14)	**8**	**9**	**8**	**5**	**8**

Table 3.2: Pheromone Brands of Commercially-Available Dogwood Borer Lures Used in 2003 Trials

Brand of Lure	Load Rate	Pheromone Components	Manufacturer
SC-L119 ("Sentry")	12 mg/ml	Z,Z-3,13-octadecadienyl acetate	Scentry, Inc., Billings, MT
L3-4027/000 ("Phero Tech")	250 µg/ml	Z,Z-3,13-octadecadienyl acetate	Phero Tech, Inc, Delta, British Columbia, CAN
DWB Lure ("IPM Tech")	1 mg/ml	Z,Z-3,13-octadecadienyl-1-ol acetate	IPM Tech, Inc., Portland, OR
Scenturion 149 ("Scenturion")	1 mg/ml	100:1 E,Z-2,13-octadecadienyl acetate Z,Z-3,13-octadecadienyl acetate	Suterra LLC, Bend, OR
European Test-Blend ("European")	1 mg/ml	96% Z,Z-3,13-octadecadienyl acetate 4% E,Z-3,13-octadecadienyl acetate small amounts of Z,Z-2,13-18Ac & E,Z-2,13-18Ac	Great Lakes, IPM, Vestaburg, MI

Figures

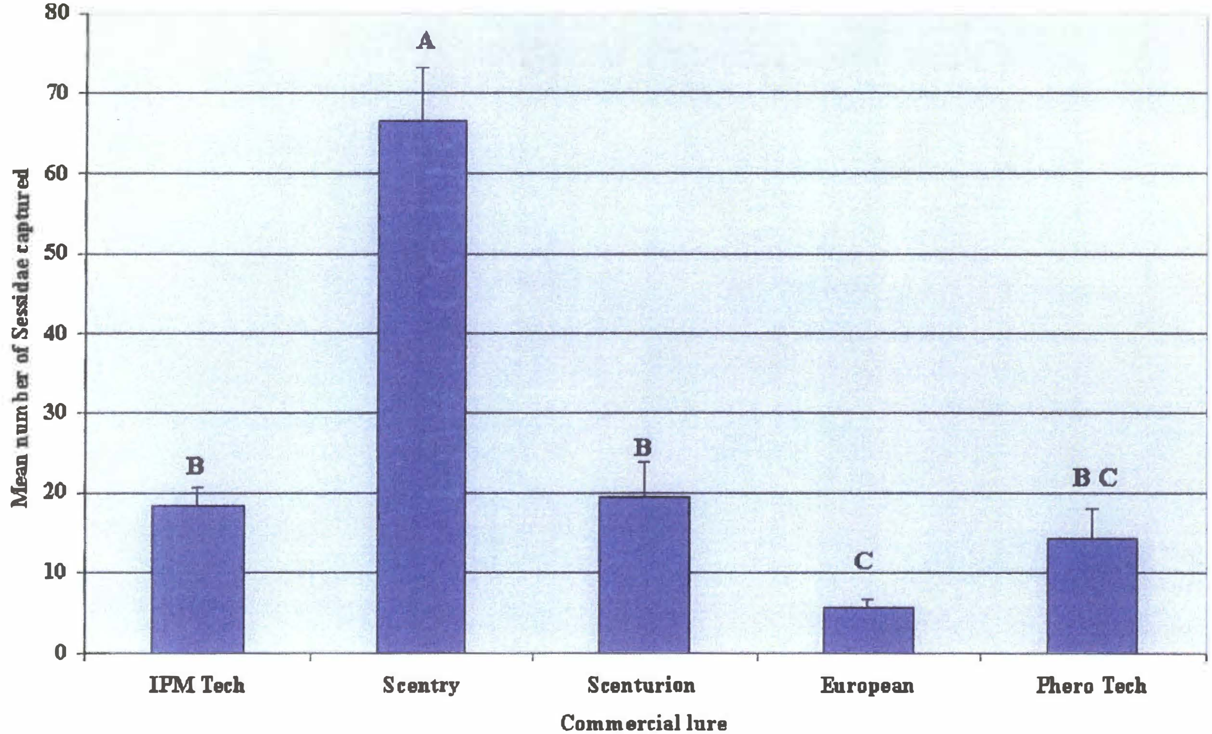

Figure 3.1: Represents the Total Sesiidae Collected in Brand of Lure Trial, 2003. Values represent least significant difference (LSD) calculated by the comparisonwise error rate in SAS. Error bars reflect the standard error of the mean. Means with no similar letters are different by LSD separation (*P*=0.05).

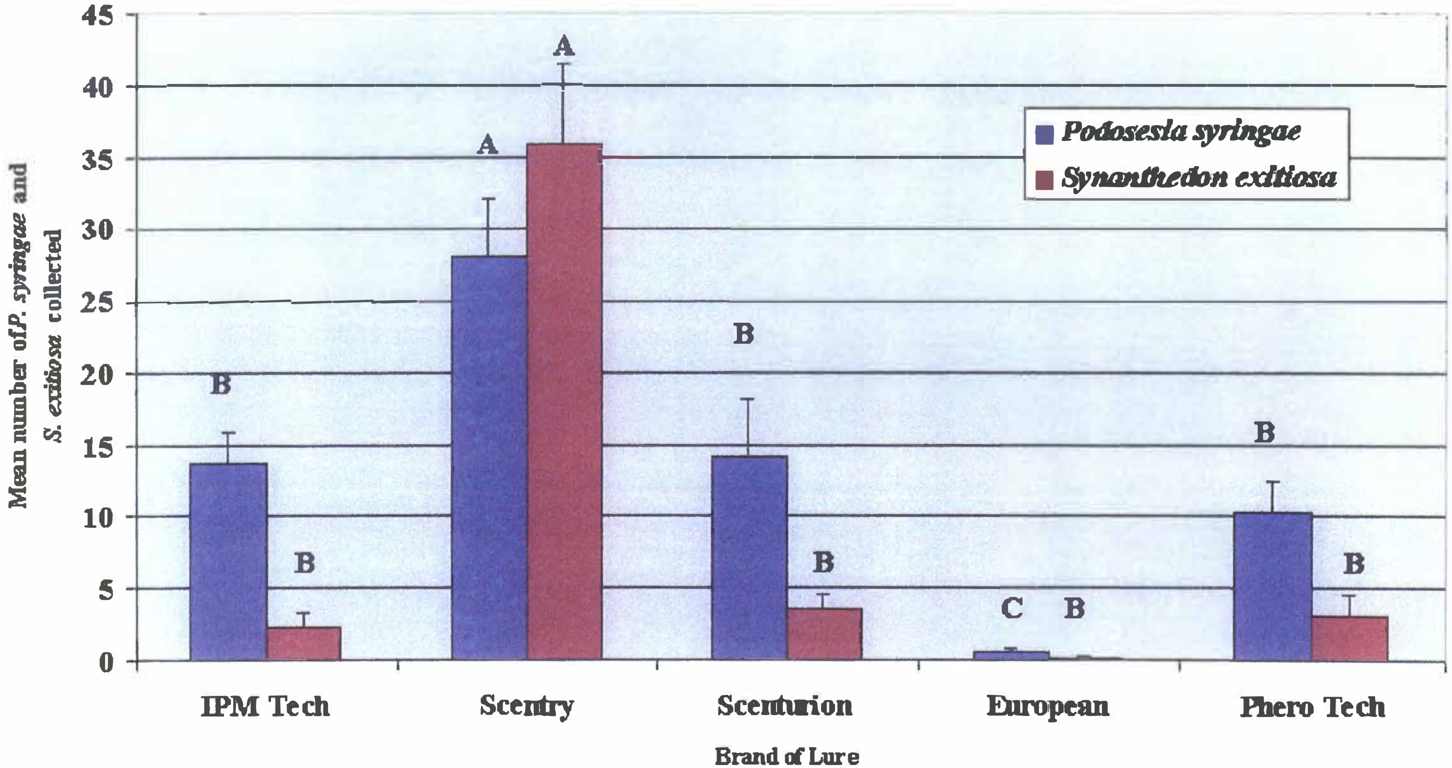

Figure 3.2: Total *Podosesia syringae* and *Synanthedon exitiosa* Collected During Lure Brand Trial, 2003. Values represent least significant difference (LSD) calculated by the comparisonwise error rate in SAS. Error bars represent the standard error of the mean. Means within species that do not have similar letters are different by LSD separation (*P*=0.05).

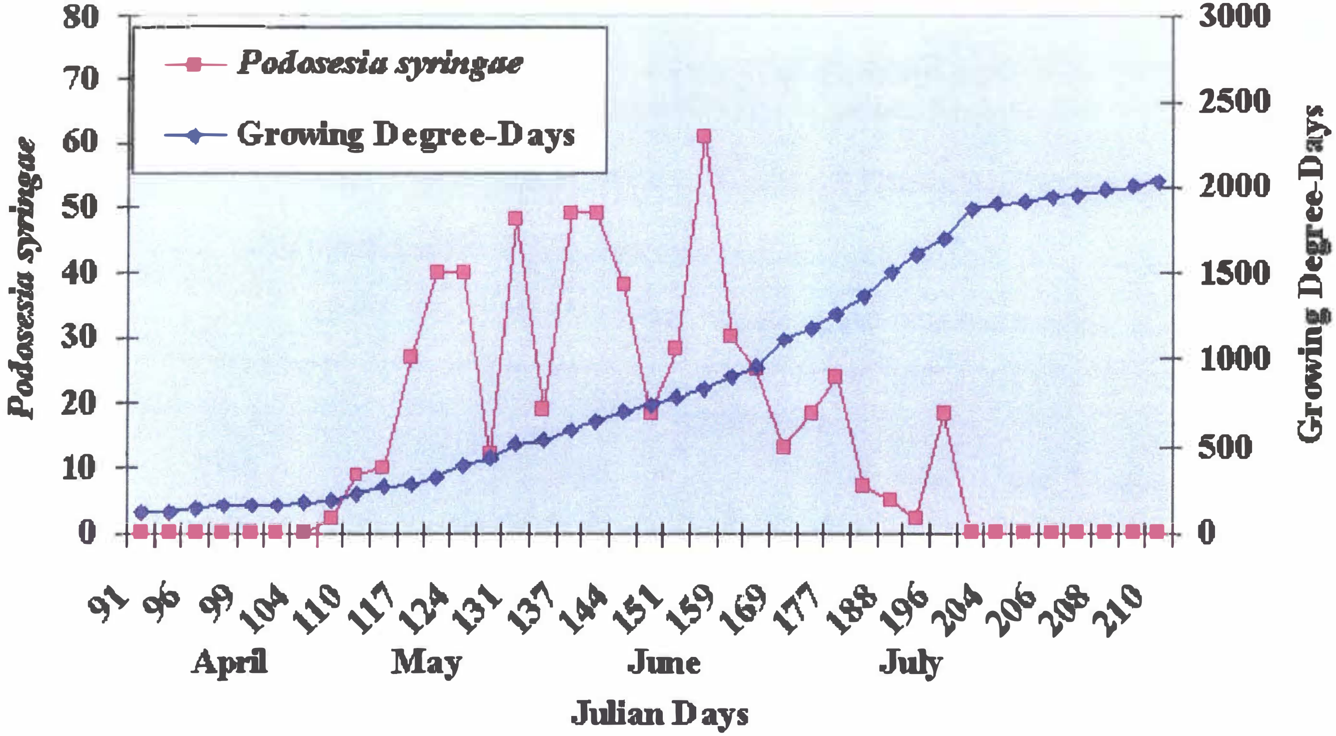

Figure 3.3: Seasonal Flight Activity of *Podosesia syringae*, 2003.

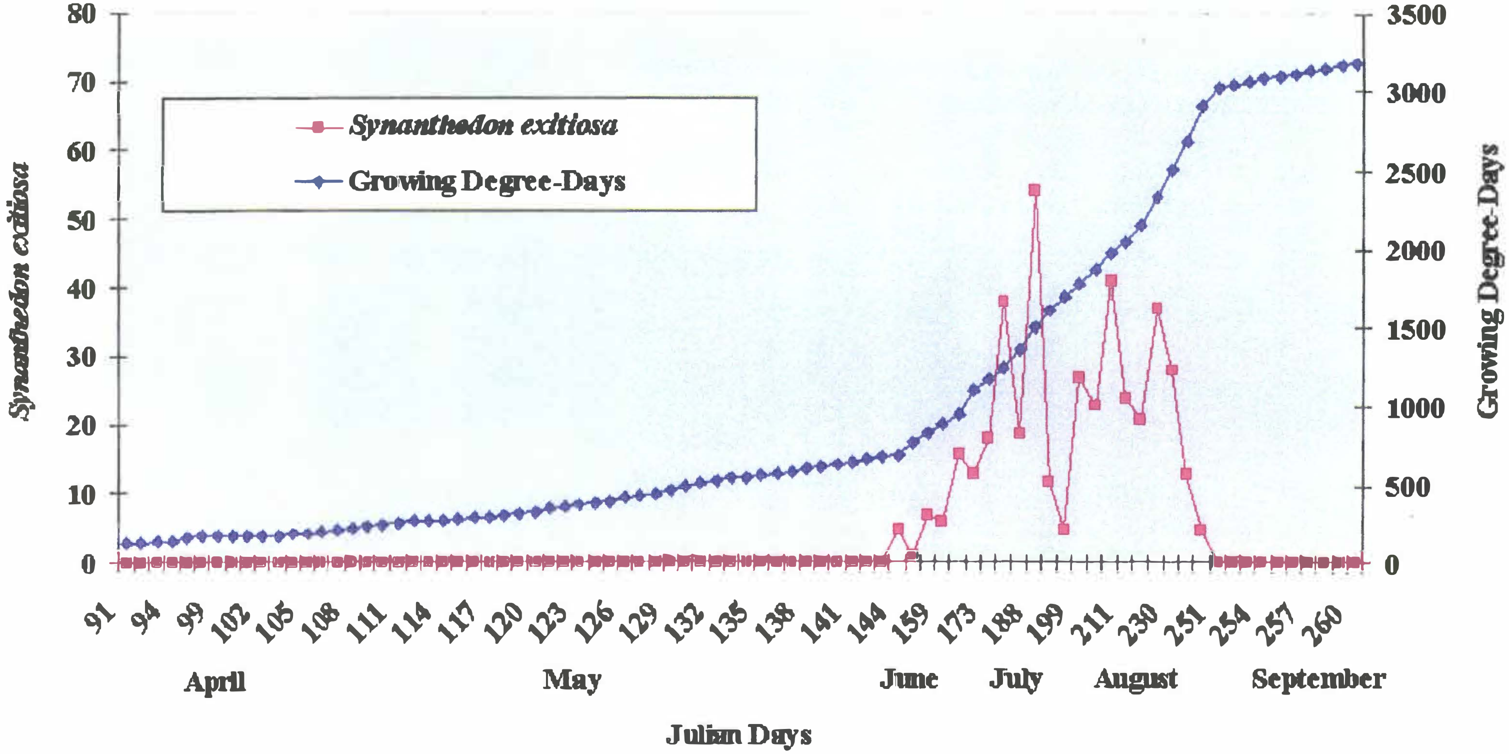

Figure 3.4: Seasonal Flight Activity of *Synanthedon exitiosa*, 2003.

Part 4: Conclusions

The responsibilities of landscape maintenance companies are no longer defined just by landscape installation and mowing. Landscape professionals also monitor and control pest populations within the landscape. Environmental regulations and public concern over the use of pesticide are influence the way that landscapes are treated. The general trends of applying chemical pesticides on a preventive/curative method have raised societal concerns of health and safety of our children, potential ground water contamination, exposure of non-targeted organisms, and development of pesticide resistance. Many grounds maintenance companies are adopting Integrated Pest Management (IPM) to limit the potential for over-reliance of pesticides in the biosphere. Integrated pest management has demonstrated to be a desirable approach to pest management in urban landscape and limiting the over-reliance of pesticides. The goal of IPM is not the eradication of all pests but rather to maintain pest populations below an economic or aesthetic injury threshold. The success of IPM requires proper identification of the target pest and determination of when to properly apply a pesticide. Consistent and frequent evaluation is vital to any successful IPM program. After any control measure is implemented, IPM evaluation should be conducted during the next scheduled monitoring visit. IPM evaluation should include quantitative and qualitative assessments of pest population density, density of beneficial, the quality, value of the plant, both before and after treatment and all relative costs i.e. time, chemical usage, and environmental impacts of the program of the treatment regimen.

The dogwood borer, *Synanthedon scitula* (Harris), is considered to have the broadest host range of all sesiid. It is an economically important pest of many ornamental, fruit, and nut trees. Pheromone baited traps are a monitoring tool that allows IPM scouts the ability to properly identify and pinpoint the first emergence of adult male clearwing moth borers. This knowledge helps accurately time insecticide applications and to maximize their efficacy. The Master's research project sought to: 1) evaluate trap color preference of male sesiid moths using Multipher-1 traps 2) clarify the diversity of clearwing species captured using commercially-available pheromone lures marketed to capture the dogwood borer, and 3) to forecast the seasonal emergence and flight activity of male clearwing borers.

The results of this study will directly benefit homeowners and Green Industry professionals in east Tennessee. In 2003, clearwing moth trap catches were pooled across species and analyzed by black, green and white painted traps. The color of traps did not influence the numbers of adult male sesiid moths captured.

A simultaneous study at three study sites using upainted Multipher-1 traps with a white base and green top to evaluate the effectiveness of five commercially-available lures marketed to trap male dogwood borers. In fact, the commercial lures captured a total of 1,121 male moths with representatives from 14 different clearwing borer species. Of this total, only 3 individual moths were dogwood borer.

Previous studies have hypothesized possible reasons why pheromone lures do not reliably capture male dogwood borers. Explanations have included poor blend composition, variations in isomeric blends, different load rates and inconsistencies in synthesizing and manufacturing the pheromone and lures. Development and reanalysis of the female sex pheromone of *S. scitula* needs to be developed to reduce the potential damage caused by dogwood borer in both the urban and agricultural system.

However, the identity and of clearwing moth species attracted to these commercial products has been documented for each commercially-available brand. Many of these species look very similar to one another, yet have different host preferences and seasonal population densities. Often times, during this study, closely related species required specialized taxonomic assistance to determine the identity of the moth species that was captured.

A need remains to develop a detailed photographic description of species captured would be a useful tool for landscape professionals. The photographic database of taxonomic observations and species-specific identification would be a helpful addendum to "A Guide to the Clearwing Borers (Sesiidae) of the North Central United States" and "The Moths of America north of Mexico" (Taft et al., 1991; Eichlin and Duckworth, 1988).

More specifically, in 2002 and 2003, research highlighted the seasonal flight activities of both adult male lilac borers, *Podosesia syringae* (Harris) and peachtree borers, *Synanthedon exitiosa* (Say) were compared to growing degree-day (GDD) accumulations using a base temperature threshold of 50°F (10° C). The heaviest flight for lilac borer activity was between 30 April following accumulations of 320 GDD and

17 May after 582 GDD. Peachtree borer adults were trapped consistently from 6 June after 1104 GDD and 30 July following GDD 2049. The flight activity information provided by this study can help manage clearwing pest population growth, reduce chemical usage and subsequent plant damage in the urban landscape

The results of this study are expected to provide IPM scouts with a better understanding of the seasonal activity of two species of clearwing moths in eastern Tennessee. Early detection and control of clearwing moths will reduce chemical dependency by properly timing applications and prevent economic and aesthetic injury to the urban landscape. In turn, landscape management professionals will gain valuable tools that will increase their precision for timing control strategies, which will limit clearwing pest population growth and subsequent plant damage.

Vita

Christopher Dean Vaughn was born in Milwaukee, Wisconsin, on October 8, 1958. Christopher grew up in Valparaiso, Indiana, and graduated from Valparaiso High School in 1976. From there he moved to Johnson City, TN to attend East Tennessee State University and graduated in 1981. Chris started his liquid fertilization business Mr. Green Thumb, Inc. in 1982. In 2002, he decided to also undertake Master of Science in Plant Science at the University of Tennessee. Throughout, Chris has enjoyed his beautiful family Anne, his wife, and his two wonderful children, Elliot now eleven, and Max, eight years old. Chris plans on using the knowledge he gained from his Master of Science degree to further expand his fertilization company and educate his customer blend.